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# **An Investigation of the Forced Ventilation in Containership Holds**

U.S. DEPARTMENT OF COMMERCE  
National Bureau of Standards  
National Engineering Laboratory  
Center for Fire Research  
Washington, DC 20234

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Sponsored by:  
**U.S. Coast Guard  
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Howard R. Baum  
John A. Rockett

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**U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary***  
**NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director***





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## Nomenclature

$Ai$	Airy function
$C$	Vapor concentration in air
$C_o$	Equilibrium vapor concentration of spill material
$D$	Fuel diffusivity in air
$d$	Slot half width
$f$	Function defined by eq. (10)
$G$	Grashof Number
$g$	Acceleration of gravity
$h$	Slot height
$i$	Unit vector in the x direction
$j$	Unit vector in the y direction
$k$	Unit vector in the z direction
$l_n$	Length of slot "n"
$m$	Number of air changes per hour
$\dot{m}$	Local mass flux picked up, defined in eq. (73)
$\dot{M}$	Total mass flux picked up in a slot, defined in eq. (76)
$N$	Number of slots
$n$	Slot number
$\vec{n}$	Outward pointing normal to integration centre
$p^*$	Thermodynamic pressure
$p$	Perturbation due to flow pressure
$Pr$	Prandtl Number
$Q''$	Slot source flow per unit area
$Q_v$	Total flow through end void
$Q_n$	Total flow through the nth slot
$Q$	Total flow drawn through hold

q	Normalized slot flow
Re	Reynolds Number = $md^2/\nu\tau$
Sc	Schmidt Number
T	Temperature
t	time
$\vec{u}$	Gas velocity
u	Gas velocity component parallel to x
v	Gas velocity component parallel to y
w	Gas velocity component parallel to z
x	Coordinate parallel to slot or void length
y	Coordinate parallel to slot or void height
Y	Dimensionless coordinate defined in eq. (38)
z	Coordinate parallel to slot or void width
Z	Dimensionless coordinate defined in eq. (38)
$X_v, Y_v$	Location of air extractor in end void
$\delta$	Dirac Delta Function
$\xi$	Dimensionless coordinate parallel to x Also, real part of complex variable defined in eq. (25)
$\eta$	Dimensionless coordinate parallel to y Also, imaginary part of complex variable defined in eq. (25)
$\zeta$	Dimensionless coordinate parallel to z
$\rho$	Gas density
$\lambda$	Concentration layer vertical coordinate defined in eq. (66)
$\mu$	Gas viscosity
$\nu$	Gas kinematic viscosity
$\tau$	Time unit (hours) Also, complex variable defined in eq. (33)

$\Theta$	Dimensionless temperature
$\omega$	Scale factor defined in eq. (6)
$\Gamma$	Gamma function
$\psi$	Stream function defined in eq. (64)

#### Subscripts

$o$	Reference value for T, p
$l$	Value at top of hold
$n$	Value associated with nth slot
$v$	Value associated with end void

#### Superscripts

$*$	Dimensionless, perturbation values, defined in eq. (38)
$\wedge$	Dimensionless, perturbation value, defined in section 3
$\sim$	Dimensionless variables defined in eq. (20)

#### Operators

$\nabla$	Vector gradient
$\Delta$	Laplacian



# AN INVESTIGATION OF THE FORCED VENTILATION IN CONTAINERSHIP HOLDS

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## Abstract

An analysis of the fluid flow and mass transfer induced by ventilation systems in containership holds was carried out. The result of the work was used to support the U.S. position before a committee of the International Convention on Safety to Life at Sea. The analysis consists of a detailed calculation of the forced motion through an interconnected set of narrow, stably stratified vertical air passages, which represent an idealized containership hold. The results of this calculation were then used to predict the vapor concentration of spilled volatile material assumed to lie at the bottom of the vertical air passages. The result is a set of formulae which determine the rate of extraction of volatile material as a function of hold geometry, ventilation parameters, and ambient stratification. The results are incorporated in a computer program which is described in detail. A variety of computed results are presented. The results indicate the crucial importance of locating the extractor as close to the hold bottom as technically possible.

## 1. INTRODUCTION

The purpose of this study was to obtain the information necessary to prepare a quantitative statement on the degree of fire hazard that might exist in the hold of a large containership as a function of the amount and nature of the hold ventilation and amount and kind of leakage of flammable liquid or gas cargo. The effort was mainly analytic although some scale model tests were

conducted. Sea tests were conducted by Sealand Corporation to determine the degree to which the thermal conditions assumed by the analysis were found in practice.

Containerships play a major role in the U.S. Merchant Marine. The majority of the non-bulk sea-going cargo into and out of the U.S. is now moved in containers. Some of this cargo is classified as "dangerous cargo", such as flammable liquids and gases and are regulated in treaty provisions based on recommendations of the International Maritime Consultative Organization (IMCO).

Under existing regulations stowage limitations, resulting from the types and amounts of cargo classed as dangerous, reduce shipment scheduling flexibility. IMCO has considered new regulations which would somewhat relax the dangerous category definitions for ships with adequate hold ventilation or detection and inerting systems. The basis for their action is the belief, by some members of the committee, that ventilation would keep the concentration of leaking and vaporizing flammable gas below the flammable or explosive limit. However, prior to this study, there did not appear to be a rational basis for establishing a suitable rate of ventilation. A study on the scale of this one could not address the full range of situations which might arise but the most prevalent situation was considered. Using the results of this study a position was developed and presented by the U.S. representative to IMCO as a counter to the ad hoc opinions originally put forward by others. After discussion, a position close to the U.S. position was adopted by the committee.

Container freight forwarding is a highly automated process using ships often specifically built for container freight and complex dock side equipment matched to the ship design. Containers of a uniform size are closely stacked within the holds, filling all the space available after allowance for structure, container guides and spaces at the sides, especially near the ends of the ship, due to the non-rectangular shape of holds. Current practice loads a hold to its maximum capacity. In the center portion of a ship, with wing tanks occupying the space between the hull plating and the side combing of the hatch, the only significant voids would be between the top of the containers and the underside of the hatch covers; and at one end of the container stacks, where deep framing of the transverse bulkhead result in a array of rectangular spaces interconnected by lightening holes in the frames. The spaces between stacks of containers, between the containers and the wing tank walls, or between the end of the container stacks and the smooth (non-framed) side of a transverse bulkhead would be only that needed for the container guides, typically about 10 cm between stacks of containers and half this between the containers and bulkhead, see figure 1. On some ships there may be fixed, heavy longitudinal beams to support the hatch cover. The gaps between container stacks on either side of such a beam would be somewhat wider. Where wing tanks are not used and at the ends of the ship, a fairly large void will exist between the hull plating and the outermost container stack. This will be partially subdivided by the transverse and longitudinal framing. The container stacks rest on the flat, smooth double bottom tank top. Although an air space some 10 cm deep exists under the containers this is cut off from the inter-container gaps and end void by side and end rails or skirts of the container so that effective communication with this space is limited by the thickness of the corner pads of the containers, a gap perhaps



less than 2 cm. Should a liquid be spilled on the tank top it would be able to flow under the containers as the ship rolled but liquid evaporated under the containers would not easily escape to the rest of the hold.

The accident scenario envisaged involves a container carrying general cargo including some flammable liquid in cans or drums. For any of a number of reasons -- a defective drum, inadequate dunnage and securing, rough handling of the container, etc. -- flammable liquid is assumed to escape into the interior of the container. Although a container in good condition is quite weather tight, an older container, especially if it has been roughly treated (a situation likely to accompany disruption of its cargo), may allow a liquid, spilled inside, to leak out. It is assumed that liquid does escape and flows down over the outside of the containers below to the bottom of the hold, where it accumulates in a puddle which is spread by rolling and pitching of the ship to wet the entire bottom of the compartment. In the case considered for the numerical examples used throughout this paper, the liquid is heptane and the tank top area is  $324 \text{ m}^2$ . If 208 liters (55 U.S. gallons) of liquid reached the bottom of the hold and spread uniformly over the tank top, the liquid layer would be only  $2/3 \text{ mm}$  thick.

Consider the implications of this accident first as it affects conditions inside the container and next as it affects conditions in the hold. Inside the container the air will be essentially stagnant for any plausible hold ventilation scheme. Accumulated liquid will evaporate reaching a local equilibrium concentration depending on the container temperature. Hold temperatures measured by Sealand on a run from Houston to Rotterdam [1]<sup>1</sup> in

---

<sup>1</sup> Numbers in brackets refer to references listed at the end of this report.

the fall of 1978 ranged from 10 to 28°C (50 to 83°F). From figure 2 [2] it is seen that the equilibrium vapor pressure of heptane, for these temperatures, ranges from 20 to 53 mm-Hg yielding corresponding volume concentrations of 2.6 to 7.0%. Lewis and Von Elbe [3] give the flammability limits for heptane in air as 1.2 and 6.7%. Thus the undiluted heptane vapors will lie within the flammable limits throughout the expected temperature range. Heptane ( $C_7H_{16}$ ) vapors are heavier than air. The mean molecular weight at standard temperature and pressures of the equilibrium heptane-air mixture for this range of vapor pressures is 30.84 to 34.11 compared to 28.97 for air. This will tend to inhibit mixing of the heavy vapors with the rest of this air in the container but, over a long period of time, through diffusion, a substantial volume of combustible vapor could accumulate inside the container (121 to 312 gm of heptane/ $m^3$  of air in a container with total volume about 90  $m^3$  and void volume estimated at 10  $m^3$ ). Our accident scenario supposed that the container would allow the spilled liquid to leak out but, of course, it might not, or might leak very slowly. Thus, if an ignition source of sufficient strength to ignite the vapors were found within the container, a vapor deflagration could occur followed by fire. Recall that this situation is independent of the amount and type of hold ventilation and that, for the chemical and temperatures chosen, there is little possibility of escaping danger by exceeding the rich flammable limit after a long time.

If the container leaks, some or most of the liquid can escape, possibly alleviating the hazard just described but creating another in the ship's hold. As already noted the liquid will form a thin but extensive puddle on the tank top. If there is a low point sump in the hold, a substantial amount of the spill may drain into it and could be pumped to a safe holding tank.

Such an arrangement seems the most suitable way to remove any substantial amount of liquid. However, evaporation will occur in the hold just as it does in the container, but, in the hold, ventilation can greatly reduce the hazard.

Consider first the zero ventilation situation in an unstratified hold. While, as just discussed, there might be 1 to 3 kilograms of fuel vapor in the container where the spill originated, the ship's hold is so large that, for a plausible spill volume, evaporation followed by thorough mixing might exhaust the available vapor before the lean limit concentrations were reached. For a hypothetical ship with wing tanks, i.e., minimal side voids, loaded with 10 rows of 35 foot containers across the hold each row 7 containers high, the total hold volume might be about  $6,500 \text{ m}^3$  ( $230,000 \text{ ft}^3$ ) and the void volume  $1,760 \text{ m}^3$  ( $62,000 \text{ ft}^3$ ). This void volume could carry, for the range of temperatures expected, from 210 to 550 kg heptane, or approximately the contents of 1-1/3 to 3-1/2 55 gallon drums. A very large ship without wing tanks would have considerably more void volume in its midships holds while, in the ends a ship, there could be considerably less void volume. In any event, the advantage of a low point sump becomes clearer in this context since it could remove much of the spill liquid before it evaporated. As noted earlier, the film of liquid from a 55 gallon spill, spread evenly over the tank top of a large ship is quite thin. Since some residual film, puddles in irregular low spots, etc., must be anticipated, there would be a significant reservoir for evaporation even with an efficient sump. This residual volume is difficult to estimate but, for a low viscosity liquid might be about 20 to 30 gallons in so large a space. For the void volume of our example ( $1760 \text{ m}^3$ ) at the lean limit concentration there would be 94 kilograms of heptane vapor or the result of evaporating 33 gallons. Thus, by using a sump, there is the possibility of keeping the average composition of the vapor below the flammable limit.



Although the average composition of the vapor might be kept below the flammable limits, during the evaporation process (while liquid remains) there will be a region near the liquid surface in which the vapor concentration will approach the equilibrium vapor concentration corresponding to the liquid temperature. As we have seen, this can be expected to be well within the flammable limits. The purpose of ventilation is to keep the volume of gas which is within the flammable limits as small as possible. If the air in the hold were continually stirred, for example, by natural convection created by an unstable vertical temperature gradient -- bottom of the hold warmer than the top, the same situation described under zero ventilation would apply. However, an unstable temperature gradient was observed only intermittently on the instrumented containership run from Houston to Rotterdam and then only in the upper portion of the hold. The lowest thermocouple was always the coolest. Throughout most of the voyage the hold air was stably stratified for all heights measured. In addition to the temperature stratification, if there are pools of flammable liquid at the bottom of the hold, the vapor just above these pools will be heavier than pure air. This may be expressed as an added equivalent thermal stratification by giving the temperature difference required to produce the same density difference in pure air as is produced by the fuel vapor. For heptane at the temperature observed, this ranges from about 20 to 50°C. By contrast the true thermal stratification on the instrumented sea run never exceeded 3°C, and was more typically less than 1°C. Thus the combination of a stable temperature field and heavy evaporated liquid vapor tends to be extremely stable near the tank top (hold bottom) and generally stable, though much less so, elsewhere.

If there were a transverse temperature difference, one side of the hold warmer than the other, a circulation would develop [4,5]. In an empty hold a narrow boundary layer flow would move up the warmer side across the top of the hold and down the cooler side. Near-stagnant conditions would be found in the interior of the hold. The flow across the tank top would also be confined to a thin boundary layer. In a loaded ship, due to the presence of the container stacks, this flow would be strongly inhibited except in the end void associated with the bulkhead framing and here the framing would considerably reduce the general flow. In practice, the flow induced by a transverse temperature gradient in the presence of a stable vertical gradient, would probably only be significant in the two side voids of a ship without wing tanks. The circulation would be between the sides of the ship and the outer side of the outermost container stacks. Such flow has not been considered in this study.

The flow that seems most likely to affect the vapor bubble over evaporating liquid on the tank top is that associated with forced ventilation. Obviously, for the well mixed case (unstable stratification) the location of the suction and inlet for the forced flow are relatively unimportant although they should be well separated. In the stably stratified case this is not true. Both since the stable case is more prevalent and since, in the unstable case, the suction may be located anywhere and might as well be placed advantageously for the stable situation, the stable case has been given priority in our study. With stable stratification and flammable vapors heavier than air originating from a liquid spill, the suction should be close to the bottom of the hold and the inlet placed well above it. As will be discussed in detail in the following sections, the air flow will at first spread laterally from the inlet with very limited vertical movement. There



will be a relatively slow drift downward to the level of the suction followed by lateral movement in the plane of the suction, again with little vertical motion, to the suction location. If the suction is located above the tank top (at the bottom of the hold shown in figure 1) the gas below the suction will tend to be stagnant. In the stably stratified case, vertical movement of the gas is facilitated where it can exchange heat with its surroundings. The result is that the vertical drift from the level of the inlet to that of the suction is not uniform but concentrated in thin boundary layers adjacent to the container stacks and ship structure. The more stable the stratification the narrower these boundary layers become. For the geometry and temperature differences found in a typical container ship these boundary layers are only a few centimeters thick. The result is that virtually the same flow can move down the 10 cm wide gap between container stacks as down the several meter wide gap between the outermost container stack and the side of the ship. Only when the gap is narrower than the combined thickness of the two boundary layers is the flow decreased. This may occur in the gap between the end of the container stacks and the smooth side of the bulkhead.

In all the above, the accident was assumed to involve a liquid spill. Although this appears to be the most likely type of accident, some materials could be released whose vapors are lighter than air. To deal with this eventuality, it has been proposed that the forced ventilation inlet be located near but not at the top of the hold and that a suction pulling a minor fraction of the ventilation be provided at the highest point in the hold, just under the hatch cover.

## 2. BASIC ASSUMPTIONS OF THE THEORETICAL MODEL

In order to develop a quantitative model, it is necessary to know the geometry and thermal stratification of a typical container ship hold. The most obvious feature of such holds (on efficiently designed ships) is that most of the available space is occupied by containers. The only air spaces are narrow vertical slots between stacks of containers, similar but less narrow voids at ends and/or sides of the stacks, and a gap between the top of the container stacks and the hatches. The size and shape of these vary from ship to ship, and from one hold to the next on a given ship. The temperature distribution in each hold is dependent on both the ship and its thermal environment over a period of time. In general, the environment is highly dependent on the ships route and both seasonal and daily weather patterns. The conditions prevailing in tanks adjacent to the hold are also important and may vary markedly during a voyage. Given this environment, the complete determination of the thermal balance on a ship is itself a formidable task.

Rather than attempt to model the detailed features of a single hold and thermal environment, a set of simplifying assumptions is introduced, which permits the analysis to be reduced to a tractable size and scope, and still retain some dependence on the physical and geometric parameters described above. These assumptions are:

- (1) The hold is rectangular. The air spaces consist of narrow rectangular vertical slots separating container stacks and a narrow rectangular vertical void at one end of the hold. The idealized hold is shown schematically in figure 3.

(2) The temperature distribution in the hold is stably stratified and varies linearly from top to bottom. The containers and ship hull are in thermal equilibrium with this distribution. Thus, all motions are due to ventilation.

(3) The ventilation system is designed so that air enters at the top of the hold and exits in the end void. The overall air volume flow is consistent with creeping motion (inertia forces unimportant).

Finally, in order to estimate the rate at which spilled material is picked up it is necessary to impose a spill scenario on the model. It is assumed that the spill material collects at the bottom of the slots between container stacks. The material is picked up as vapor in a concentration boundary layer formed at the bottom of the slot. All material caught up in this boundary layer is assumed to exit with the ventilation air. The analysis then proceeds as follows:

First, the conditions for low Reynolds number flow are established and the small scale motion in a single slot is determined. This leads to an equation for the pressure that governs the large scale motion in a single slot. This equation is then solved assuming that the pressure in the end void where the flow exits is known. The next step is the solution for the pressure in the end void, which ties together the large scale motion in the entire hold. Then the local flow in the bottom of each slot is obtained. The final step is the calculation of the concentration boundary layer in the slot bottom, which determines the actual pickup of spill material.

### 3. SLOT FLOW IN A STABLY STRATIFIED ENVIRONMENT

As mentioned above, the volume available for air movement in a container-ship hold may be usefully idealized as a collection of narrow vertical and horizontal slots. The analysis of the motion in a single slot is thus a necessary precondition for a study of the air movement throughout the hold. In order to proceed, we must first establish that the creeping flow regime is encountered for realistic values of the governing flow parameters. Then, approximate solutions to the equations of motion valid in the appropriate flow regime can be constructed. Finally, these solutions will be related to the large scale motion in the hold.

Consider a vertically oriented slot of width  $2d$ , height  $h$  and length  $\ell$  (figure 4). The equations governing the steady motion of a viscous incompressible fluid affected by buoyancy forces can be written in the Boussinesq approximation as:

$$\nabla \cdot \vec{u} = 0$$

$$(\vec{u} \cdot \nabla) \vec{u} + \frac{1}{\rho} \nabla p^* + \left( \frac{T - T_o}{T_o} \right) \vec{g} = \nu \Delta \vec{u} \quad (1)$$

$$(\vec{u} \cdot \nabla) T = (\nu/Pr) \Delta T$$

Here  $\vec{u}$  is the velocity vector,  $p^*$  the pressure, and  $T$  the temperature in the fluid. The density  $\rho$ , kinematic viscosity  $\nu$  and Prandtl number  $Pr$  are properties of the fluid taken as constant corresponding to the hold bottom



temperature  $T_0$ . The gravitational acceleration  $\vec{g}$  is directed vertically downward, while  $\nabla$  and  $\Delta$  are respectively the gradient and Laplacian operators.

Equation (1) represents the conservation of mass, momentum, and energy respectively. It is anticipated that the ventilation system will be designed to induce mean (mass averaged) velocities in the slot whose order of magnitude is such that air actually in the hold bottom can be swept out several times per hour. Let  $m$  be the number of times per hour that a slot is swept out horizontally. Then a typical horizontal velocity must be of order  $m\ell/\tau$ , where  $\tau$  is the period (one hour). The inertial terms (the non-linear terms) in the horizontal momentum balance are then of order  $(m\ell/\tau)^2/\ell$ ; while the viscous terms are of order  $\nu(m\ell/\tau)/d^2$ . The ratio of these two terms indicates the relative importance of viscous and inertial effects. It will be called the "effective Reynolds number" in this report to distinguish it from more conventionally defined Reynolds numbers. This effective Reynolds number ( $Re$ ) for horizontal motion in the slot, which determines the flow regime of interest, is given by

$$Re = \frac{md^2}{\nu\tau}.$$

For slot widths and sweep rates of interest the effective Reynolds number  $Re$  is typically in the range  $1 \leq Re \leq 10$ .

For this range of values, the horizontal flow is effectively one in which the pressure forces balance the viscous forces on the fluid, as in pipe flow and in bearing lubrication [6,7]. This occurs because the slot is so narrow in comparison to its length ( $d/\ell \ll 1$ ) that velocities perpendicular to the

plane of the slot (i.e. - in the z-direction, see figure 4) are negligibly small compared with those in the plane of the slot. Although the above argument strictly applies to horizontal motions, it will be shown in detail below that the effect of stable stratification will be to reduce even further the importance of inertial effects on the fluid motion.

We now turn to a detailed study of the motion in the slot. Let  $P_0$  and  $T_0$  be reference values of the pressure and temperature of the air in the slot. The fluid velocity  $\vec{u}$  may be expressed in component form (see figure 4) as:

$$\vec{u} = u\vec{i} + v\vec{j} + w\vec{k}.$$

The dependent variables describing the state of motion may be represented as follows:

$$p^* = p_0 - \rho g y + \rho \left( \frac{T_1 - T_0}{T_0} \right) \frac{g h}{2} \left( \frac{y}{h} \right)^2 + p(x/\ell, y/h)$$

$$T = T_0 + (T_1 - T_0) y/h + \theta(x/\ell, y/h, z/d)$$

$$u = u(x/\ell, y/h, z/d) \tag{2}$$

$$v = v(x/\ell, y/h, z/d)$$

$$w = w(x/\ell, y/h, z/d)$$

Here,  $g$  is the magnitude of the gravitational acceleration and  $p$  is the dynamical part of the pressure. The remaining terms in the expression for  $p^*$  are the hydrostatic values of the pressure. The term linear in  $(y/h)$  in the expression for the temperature is the ambient stratification of the hold. This stratification is assumed to vary linearly between the upper temperature  $T_1$  and  $T_0$ , where  $T_1 > T_0$ . The velocity component normal to the plane of the slot,  $w$ , is smaller than the in-plane components  $u$  and  $v$  by a factor  $d/\ell$  or  $d/h$ . The conservation of momentum in the  $z$  direction immediately leads to the conclusion that the dynamic pressure  $p$  must be nearly independent of  $z$ .

It is convenient to work with non-dimensional variables defined as follows:

$$\begin{aligned} p &= (Re)\rho gh \left( \frac{T_1 - T_0}{T_0} \right) \hat{p}(\xi, \eta) \\ v &= (Re)gd \left( \frac{T_1 - T_0}{T_0} \right) \hat{v}(\xi, \eta, \zeta) \\ \theta &= (Re)(T_1 - T_0) \hat{\theta}(\xi, \eta, \zeta) \end{aligned} \tag{3}$$

$$\xi = x/\ell, \quad \eta = y/h, \quad \zeta = z/d$$

Substitution of the non-dimensional variables defined in equation (3) into the vertical momentum and energy conservation equations and neglecting terms of order  $(d/h)^2$ ,  $(d/\ell)^2$ , or  $Re$  yields:

$$\begin{aligned}
\frac{\partial \hat{p}}{\partial \eta} - \hat{\theta} &= (G)^{-1/2} \frac{\partial^2 \hat{v}}{\partial \zeta^2} \\
\hat{v} &= \frac{(G)^{-1/2}}{\text{Pr}} (h/d) \frac{\partial^2 \hat{\theta}}{\partial \zeta^2} \\
G &= \left( \frac{T_1 - T_0}{T_0} \right) \frac{gd^3}{\nu^2}
\end{aligned} \tag{4}$$

The dimensionless parameter  $G$ , the Grashof number, is the fundamental parameter controlling the nature of the vertical motion in the slot. Its influence will be discussed in detail below.

Since  $p(\xi, \eta)$  is independent of  $\zeta$ , equation (4) can be solved for the dimensionless vertical velocity  $v$  and temperature perturbation  $\hat{\theta}$  as functions of the vertical pressure gradient  $\frac{\partial p}{\partial \eta}$ . The boundary conditions associated with equation (4) are:

$$\begin{aligned}
\hat{v}(-1) &= \hat{v}(1) = 0 \\
\hat{\theta}(-1) &= \hat{\theta}(1) = 0
\end{aligned} \tag{5}$$

The physical meaning of equation (5) is that the vertical velocity and temperature perturbation must vanish at the sides of the slot. The first boundary condition follows from the no-slip condition. The second comes from the assumption that the ambient stratification in the slot is controlled by the temperature distribution in the containers, which varies linearly with height.

The solution to equations (4) and (5) is given by:



$$\hat{v} = \frac{\partial p}{\partial \eta} (h/dPr)^{1/2} \{a(\omega) \cos(\omega\zeta) \cosh(\omega\zeta) - b(\omega) \sin(\omega\zeta) \sinh(\omega\zeta)\}$$

$$\hat{\theta} = \frac{\partial p}{\partial \eta} \{1 + a(\omega) \sin(\omega\zeta) \sinh(\omega\zeta) + b(\omega) \cos(\omega\zeta) \cosh(\omega\zeta)\}$$

$$a(\omega) = - \frac{\sin(\omega) \sinh(\omega)}{-\sin^2(\omega) + \cosh^2(\omega)} \quad (6)$$

$$b(\omega) = - \frac{\cosh(\omega) \cos(\omega)}{-\sin^2(\omega) + \cosh^2(\omega)}$$

$$\omega = \frac{1}{\sqrt{2}} (GPrd/h)^{1/4}$$

It should be noted that the above solution, while approximate in terms of the overall problem of interest, is in fact an exact solution of the equations of hydrodynamics for an infinitely long slot. This buoyancy layer was first found by Prandtl [8], and by Gill [9], and used by Gill [9], in his analysis of thermally driven slot convection. Gill's analysis has been experimentally verified by Elder [10]. In the present application, the solution corresponds to a forced stratified channel flow. In the limit of zero stratification:

$$\hat{v} = - \frac{\partial p}{\partial \eta} (h/dPr)^{1/2} \omega^2 (1-\zeta^2). \quad (7)$$

Returning to dimensional variables, equation (7) can be rewritten in the classical form:

$$v = - \frac{1}{2} \frac{d^2}{\mu} \frac{\partial p}{\partial y} [1-(z/d)^2]; \quad u = - \frac{1}{2} \frac{d^2}{\mu} \frac{\partial p}{\partial x} [1-(z/d)^2] \quad (8)$$

Here,  $\mu$  is the viscosity of the air, and the solution for  $u$  has been added. For large stratification,  $\omega$  is not small. As an example, for a stable stratification  $T_1 - T_0$  of  $3^\circ\text{C}$ , with the reference temperature  $T_0 = 300^\circ\text{K}$  and a slot half width of 10 cm and width to height ratio  $d/h = .01$ ,  $\omega = 5.3$ . For values of  $\omega > 3$ , equation (6) simplifies to the form:

$$\hat{v} = -\frac{\partial p}{\partial \eta} (h/dPr)^{1/2} \{e^{-\omega(1-\zeta)} \sin[\omega(1-\zeta)] + e^{-\omega(1+\zeta)} \sin[\omega(1+\zeta)]\} \quad (9)$$

Equation (9) represents a vertical flow that has effectively ceased except for a boundary layer of thickness  $(\omega)^{-1}$  near each wall of the slot. Thus, for a given pressure gradient, there is much less vertical flow in the presence of stratification than in its absence. This can be seen more dramatically by calculating the vertical volume flux of air per unit of length. The vertical flux in dimensional variables is given by:

$$\int_{-d}^d v dz = \frac{2d^3}{3\mu} \frac{\partial p}{\partial y} f(\omega) \quad (10)$$

$$f(\omega) = \frac{3}{8\omega^3} \frac{\sinh(2\omega) - \sin(2\omega)}{-\sin^2(\omega) + \cosh^2(\omega)}$$

This should be compared with the horizontal volume flow per unit of height, which is:

$$\int_{-d}^d u dz = \frac{-2}{3} \frac{d^3}{\mu} \frac{\partial p}{\partial x} \quad (11)$$

Clearly, the function  $f(\omega)$  is a measure of the effectiveness of the pressure gradient in producing a vertical flow. The function is presented in table 1. The decrease in effectiveness with increasing stratification (increasing  $\omega$ ) is quite obvious.

The final stage of this part of the calculation is the determination of the pressure in the slot. The pressure distribution is governed by the requirement that mass be conserved in the slot. Let the quantity  $Q''(x,y) dA$  be the rate at which fluid is introduced by some external agent into the slot, where  $dA$  is the element of surface across which the fluid crosses. This may be an inlet or exit from a ventilation system or vent, or a cutout in an end wall. Using equations (10) and (11), the conservation of mass yields the following equation for the pressure:

$$\frac{\partial^2 p}{\partial x^2} + f(\omega) \frac{\partial^2 p}{\partial y^2} = - \frac{3}{2} \frac{\mu}{d^3} Q''(x,y) \quad (12)$$

There are three situations covered by equation (12) which are of interest. First, if there is no opening into or out of the slot, then  $Q'' = 0$ . Second, if the flux through the opening is specified, then  $Q''$  is a prescribed function. One such case of practical interest is a small opening at  $x = x_0$ ,  $y = y_0$  which a total flow rate  $Q_0$  is specified, the dimensions being small compared with the length or height of the slot. Then,  $Q''$  is given by:

$$Q''(x,y) = Q_0 \delta(x-x_0) \delta(y-y_0) \quad (13)$$

Here,  $\delta$  denotes the Dirac delta function. Finally, if the opening is large and the pressure is specified at the opening, then it is more convenient to consider the boundary of the opening as a boundary of the slot along which the pressure is specified. Then  $Q'' = 0$  as before over the interior of the region of interest. However, the solution now must be obtained over the rectangular slot, with the correct pressure being specified at the open edge. The second

and third cases are complementary in that the flow is specified and the pressure is calculated in the second instance; while the pressure is specified and the flow is calculated in the third.

#### 4. THE SLOT PRESSURE DISTRIBUTION

The starting point for the analysis is equation (12), with  $Q'' = 0$ . The boundary condition at the closed end of each slot is (see equation (11) and figure 4):

$$\frac{\partial p}{\partial x} (\ell/2, y) = 0 \quad (14)$$

At the open end, the pressure must be compatible with the end void pressure at that height. If the end void pressure at the  $n^{\text{th}}$  slot is denoted by  $p_v(n, y)$ ; then the boundary condition at the open end is:

$$p(-\ell/2, y) = p_v(n, y) \quad (15)$$

At the bottom, since there is no flow through the floor of the hold, the boundary condition is (see equation (10)):

$$\frac{\partial p}{\partial y} (x, 0) = 0 \quad (16)$$

Rather than consider the geometry of the air gap at the top of the hold and its interaction with the upper boundary of the slot, it is more convenient to note that most cases of practical interest correspond to values of  $\omega$  (see equation (6)) such that  $f(\omega) \ll 1$ . If  $\ell/h$  is of order unity, then equations

(12) and (14) imply that, away from the top or bottom of the slot,  $p$  depends only on  $y$ . Let  $Q_n$  be the total flow of air drawn through the  $n^{\text{th}}$  slot. Then equation (10) and (12) imply that the pressure distribution over most of each slot is given by:

$$p = \frac{3}{2} \mu Q_n y / d_n^3 \ell_n f(\omega_n) \quad (17)$$

Now the same relation must hold in most of the end void, away from the top or bottom. This means that the total flow,  $Q$ , drawn through the hold by the ventilation system can be related to  $p$  by the formulae:

$$Q \equiv \sum_{n=0}^N Q_n = \frac{2}{3} \frac{p}{y} \sum_{n=0}^N d_n^3 \ell_n f(\omega_n) \quad (18)$$

The sum in equation (18) is assumed to extend over all slots and the end void. Eliminating the pressure from this expression yields the result:

$$Q_n = Q \ell_n d_n^3 f(\omega_n) / \sum_{n=0}^N d_n^3 \ell_n f(\omega_n) \quad (19)$$

Equation (19) is extremely important in what follows. It permits the flow in each slot to be related to the total flow drawn through the hold,  $Q$ . Thus, since  $Q$  is a prescribed system parameter,  $Q_n$  can be determined in advance as a function of the hold geometry and stratification. Physically, equations (17)-(19) mean that the stratification completely suppresses horizontal motion everywhere except near the top and bottom of each slot and the end void. Equation (12) then implies that the horizontal motion is only important in layers of order  $\ell_n \sqrt{f(\omega_n)}$  in height near the top and bottom. The details of the motion near the top are of no interest. The only thing that



matters is that the ventilation air enters there. The bottom horizontal motion must be calculated because it determines the pickup of evaporated spill material. However, it can now be calculated as if the slot were semi-infinite in height with the boundary condition as  $y \rightarrow \infty$  given by equation (17).

To carry out the calculation, it is appropriate to proceed more formally. Let the pressure in the  $n^{\text{th}}$  slot be made non-dimensional as follows:

$$p = \frac{3}{2} \frac{\mu}{d_n^3} \frac{Q_n}{\sqrt{f(\omega_n)}} \tilde{p}(\tilde{x}, \tilde{y}) \quad (20)$$

$$\tilde{x} = x/\ell_n; \quad \tilde{y} = y/\ell_n \sqrt{f(\omega_n)}$$

Then the boundary value problem can be stated in the form:

$$\frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} + \frac{\partial^2 \tilde{p}}{\partial \tilde{y}^2} = 0$$

$$\frac{\partial \tilde{p}}{\partial \tilde{x}} (1/2, \tilde{y}) = 0$$

$$\frac{\partial \tilde{p}}{\partial \tilde{y}} (\tilde{x}, 0) = 0 \quad (21)$$

$$\lim_{\tilde{y} \rightarrow \infty} \tilde{p}(\tilde{x}, \tilde{y}) = \tilde{y}$$

$$\tilde{p}(-1/2, \tilde{y}) = \tilde{p}_v(n, \tilde{y})$$

Since the dimensionless end void pressure  $\tilde{p}_v(n, \tilde{y})$  is unknown at this point; it is desirable to seek the solution in a form which displays the dependence on  $\tilde{p}_v(n, \tilde{y})$  explicitly. This can be done with the aid of a Greens function  $G(\tilde{x}, x_o, \tilde{y}, y_o)$ , defined as the solution of the problem:

$$\frac{\partial^2 G}{\partial \tilde{x}^2} + \frac{\partial^2 G}{\partial \tilde{y}^2} = \delta(\tilde{x} - x_o) \delta(\tilde{y} - y_o)$$

$$\frac{\partial G}{\partial \tilde{x}} (1/2, \tilde{y}) = \frac{\partial G}{\partial \tilde{y}} (\tilde{x}, o) = 0 \quad (22)$$

$$G(-1/2, \tilde{y}) = \lim_{\tilde{y} \rightarrow \infty} G(\tilde{x}, \tilde{y}) = 0$$

The quantity  $\delta$  in equation (22) denotes the Dirac delta function. Introduce  $p$  and  $G$  as defined by equations (21) and (22) into the divergence theorem in the form:

$$\oint (\tilde{p} \Delta G - G \Delta \tilde{p}) dx_o dy_o = \oint (\tilde{p} \frac{\partial G}{\partial n_o} - G \frac{\partial \tilde{p}}{\partial n_o}) dS_o \quad (23)$$

Here  $n_o$  denotes the outward pointing normal to the closed contour composed of the slot boundaries and a fixed large value of  $y_o$ . Now letting  $y_o \rightarrow \infty$  and using equations (21) and (22), a formal solution is obtained for the slot pressure  $\tilde{p}(\tilde{x}, \tilde{y})$  as:

$$\tilde{p}(\tilde{x}, \tilde{y}) = - \int_o^{\infty} \tilde{p}_v(n, y) \frac{\partial G}{\partial x_o} (-1/2, y_o; \tilde{x}, \tilde{y}) dy_o \quad (24)$$

In order to make equation (24) useful, it is necessary to determine  $G$  and  $\tilde{p}_v$ . The solution for  $G$  is independent of  $\tilde{p}_v$ , and only involves the slot geometry. The solution for  $\tilde{p}_v$  will be obtained in the next section. The

Greens function  $G(\tilde{x}, \tilde{y}, x_0, y_0)$  can now be obtained with the aid of a sequence of conformal mappings. The steps in the sequence are (see figure 5 for sketches of the mappings):

$$\begin{aligned} \text{i) } \tau &= \sin (\pi \zeta) \\ \zeta &= \tilde{x} + i\tilde{y} \end{aligned}$$

This transforms the slot into a half space with the open end of the bottom at  $\tau = -1$  (figure 5b).

$$\text{ii) } \tau_1 = \tau + 1$$

This moves the open end of the bottom to the origin (figure 5c).

$$\text{iii) } W = \xi + i\eta = (\tau_1)^{1/2}$$

This converts the slot into a quarter plane with the open end on the positive imaginary axis (figure 5d). Thus:

$$W = \xi + i\eta = 1 + \sin (\pi \zeta)^{1/2}$$

$$\xi = \{(a + \sqrt{a^2 + b^2})/2\}^{1/2}$$

$$\eta = \{(\sqrt{a^2 + b^2} - a)/2\}^{1/2} \quad (25)$$

$$a = 1 + \sin (\pi \tilde{x}) \cosh (\pi \tilde{y})$$

$$b = \cos (\pi \tilde{x}) \sinh (\pi \tilde{y})$$



The Greens function can be written down immediately in the  $W$  plane. A solution is required with a logarithmic singularity at a point  $\tilde{x} = x_0, \tilde{y} = y_0$  which vanishes for  $\xi = 0$  and whose normal derivative vanishes for  $\eta = 0$ . The solution must be odd in  $\xi$  and even in  $\eta$ . The result is readily obtained in complex form as:

$$G + iJ = \frac{1}{2\pi} \{ \log(W - W_0) + \log(W - \bar{W}_0) - \log(W + \bar{W}_0) - \log(W + W_0) \}$$

$$W_0 \equiv W(x_0, y_0) = \xi(x_0, y_0) + i\eta(x_0, y_0) \quad (26)$$

$$\bar{W}_0 \equiv \xi(x_0, y_0) - i\eta(x_0, y_0)$$

Equations (24) and (26) constitute the solution for the pressure in the slot once the end void pressure is known. For later use, it is necessary to compute the pressure gradient along the bottom of the slot. This calculation requires considerable care, due to the nearly singular nature of the integral. The result, after considerable algebra, is:

$$\frac{\partial \tilde{p}}{\partial \tilde{x}}(x, 0) = \frac{\cos(\pi \tilde{x})}{\sqrt{1 + \sin(\pi \tilde{x})}} K(\tilde{x})$$

(27)

$$K(\tilde{x}) = \int_0^\infty \frac{d\tilde{p}_v}{dy_0}(y_0) \frac{\{\cosh(\pi y_0) - 1\}^{1/2} dy_0}{\sin(\pi \tilde{x}) + \cosh(\pi y_0)}$$

## 5. THE END VOID PRESSURE

The final stage in the determination of the large scale motion is the calculation of the end void pressure distribution. In order to proceed, it is necessary to assume that the end void can be treated in the same manner as the slots between container stacks, even though in many applications the relevant void width  $d_v$  and length  $\ell_v$  are such that the ratios  $d_v/\ell_v$  and  $d_v/h$  are not small. If these parameters are assumed to be small, then equation (12) applies, with  $x$  now measuring horizontal distance along the end void. The major difference between the slots and the end void lies in the appearance of non-trivial sources and sinks  $Q''(x,y)$  in the end void.

The slots between container stacks are "narrow compared with the length or height of the end void. Hence, the fluid issuing from them can be represented as line sources of fluid in the form:

$$Q''_{\text{slot}}(n) = Q_n \delta(x-x_n) q_n(y) \quad (28)$$

Here  $Q_n$  is the total flux issuing from the  $n^{\text{th}}$  slot, as given by equation (19),  $\delta$  is again the Dirac delta function operating at the horizontal location of the  $n^{\text{th}}$  slot, and  $q_n(y)$  determines the distribution of flow with respect to height. The distribution function  $q_n(y)$  is normalized so that:

$$\int_0^{\infty} q_n(y) dy = 1$$

The air extraction system is assumed to have physical dimensions which are small compared with the dimensions of the end void. Hence, it can be represented as a delta function sink of strength  $Q$ , since it exhausts all the air drawn into the hold. The geometry is sketched in figure (6).

The pressure in the end void is then determined by the solution to the following system of equations:

$$\frac{\partial^2 p}{\partial x^2} + f(\omega_v) \frac{\partial^2 p}{\partial y^2} = -\frac{3}{2} \frac{\mu}{d_v^3} Q''(x, y)$$

$$Q''(x, y) = \sum_{n=1}^N Q_n \delta(x-x_n) q_n(y) - Q \delta(x-x_v) \delta(y-y_v)$$

$$\frac{\partial p}{\partial x} \left( \frac{l_v}{2}, y \right) = \frac{\partial p}{\partial x} \left( -\frac{l_v}{2}, y \right) = 0 \quad (29)$$

$$\frac{\partial p}{\partial y}(x, 0) = 0$$

$$\lim_{y \rightarrow \infty} p(x, y) = \frac{3}{2} \mu Q_0 y / d_v^3 l_v f(\omega_v)$$

Here  $(x_v, y_v)$  is the location of the air extractor, and  $Q_0$  is the flow which originates in the end void, as determined by equation (19) with the void geometric parameters.

The solution procedure is similar to that employed in the previous section. The equations are made non-dimensional in the form:

$$p = \frac{3}{2} \frac{\mu}{d_v} \frac{Q_o}{\sqrt{f(\omega_v)}} \tilde{p}(\tilde{x}, \tilde{y})$$

$$\tilde{x} = x/\ell_v; \quad \tilde{y} = y/\ell_v \sqrt{f(\omega_v)}$$

$$\begin{aligned} \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} + \frac{\partial^2 \tilde{p}}{\partial \tilde{y}^2} = & - \sum_{n=1}^N \frac{Q_n}{Q_o} \delta(\tilde{x} - \tilde{x}_n) q_n(\tilde{y}) \\ & + \left( 1 + \sum_{n=1}^N \frac{Q_n}{Q_o} \right) \delta(\tilde{x} - \tilde{x}_v) \delta(\tilde{y} - \tilde{y}_v) \end{aligned} \quad (30)$$

$$\frac{\partial p}{\partial \tilde{x}} \left( \pm \frac{1}{2}, \tilde{y} \right) = \frac{\partial p}{\partial \tilde{y}} (\tilde{x}, 0) = 0$$

$$\begin{aligned} \lim_{\tilde{y} \rightarrow \infty} \tilde{p}(\tilde{x}, \tilde{y}) &= \tilde{y} \\ \tilde{y} &\rightarrow \infty \end{aligned}$$

A Greens function is again introduced, this time solving the following system of equations:

$$\begin{aligned} \frac{\partial^2 G}{\partial \tilde{x}^2} + \frac{\partial^2 G}{\partial \tilde{y}^2} &= \delta(\tilde{x} - \tilde{x}_o) \delta(\tilde{y} - \tilde{y}_o) \\ \frac{\partial G}{\partial \tilde{x}} (\tilde{x} = \pm \frac{1}{2}, \tilde{y}, \tilde{x}_o, \tilde{y}_o) &= 0 \\ \frac{\partial G}{\partial \tilde{y}} (\tilde{x}, 0, \tilde{x}_o, \tilde{y}_o) &= 0 \end{aligned} \quad (31)$$

$$\frac{\partial G}{\partial \tilde{y}} (\tilde{x}, 0, \tilde{x}_o, \tilde{y}_o) = 0$$

$$\begin{aligned} \lim_{\tilde{y} \rightarrow \infty} G(\tilde{x}, \tilde{y}, \tilde{x}_o, \tilde{y}_o) &= y \\ \tilde{y} &\rightarrow \infty \end{aligned}$$

Substitution of equations (30) and (31) into equation (23) then yields the result:



$$\begin{aligned} \tilde{p}(\tilde{x}, \tilde{y}) = & \left( 1 + \sum_{n=1}^N \frac{Q_n}{Q_0} \right) G(\tilde{x}, \tilde{y}, \tilde{x}_v, \tilde{y}_v) \\ & - \sum_{n=1}^N \frac{Q_n}{Q_0} \int_0^{\infty} q_n(\tilde{y}_0) G(\tilde{x}, \tilde{y}, \tilde{x}_n, \tilde{y}_0) d\tilde{y}_0 \end{aligned} \quad (32)$$

The solution is completed by specifying  $G$  and  $q_n$ . The Green's function is determined by noting that the first of the transformations employed in the previous section maps the end void into a half plane. The solution for  $G$  is then readily obtained as:

$$G + iJ = \frac{1}{2\pi} \{ \log(\tau - \tau_0) + \log(\tau - \bar{\tau}_0) \}$$

$$\tau = \sin(\pi\zeta) = \sin(\pi\tilde{x}) \cosh(\pi\tilde{y}) + i \cos(\pi\tilde{x}) \sinh(\pi\tilde{y}) \quad (33)$$

$$\tau_0 = \sin(\pi\tilde{x}_0) \cosh(\pi\tilde{y}_0) + i \cos(\pi\tilde{x}_0) \sinh(\pi\tilde{y}_0)$$

$$\bar{\tau}_0 = \sin(\pi\tilde{x}_0) \cosh(\pi\tilde{y}_0) - i \cos(\pi\tilde{x}_0) \sinh(\pi\tilde{y}_0)$$

The flow distribution functions,  $q_n$ , are in reality not arbitrary, but must be determined by the condition that the pressures as computed from equations (32) and (33) lead to the same flows when the solutions given by these equations are substituted into equation (24) and equation (24) is differentiated to obtain the flow out of each slot. In general, this leads to a system of  $N$  integral equations for the void pressure at each slot. The solution can be approximated with reasonable accuracy, (i.e. enough accuracy to evaluate equation (27)) by noting several points. First, the fact that the total flow issuing from each slot is known implies the constraint given by equation (30) on  $q_n(y)$ . Second, the flow should be greatest at height

$\tilde{y} = \tilde{y}_v$ , since that is the level at which the air is drawn out. Third, the flow should ultimately decay exponentially with distance away from its maximum, since the integral equations have the Greens functions for kernels, and the Greens functions all exhibit this type of decay. Finally, examination of equations (27) and (32) shows that the pressure cannot be sensitive to details of the shape of  $q_n(\tilde{y})$ . Hence, in the spirit of Carrier [11], the following form for  $q_n(\tilde{y})$  is postulated:

$$q_n(\tilde{y}) = \frac{\pi}{[2 - e^{-\pi \tilde{y}_v}]} \exp \{-\pi |\tilde{y} - \tilde{y}_v|\} \quad (34)$$

Equation (34) is consistent with all the points mentioned above. It also permits the integral in equation (32) to be evaluated in closed form. The result, after some extremely tedious algebra is:

$$\begin{aligned} \tilde{p}(\tilde{x}, \tilde{y}) = & \left( 1 + \sum_{n=1}^N \frac{Q_n}{Q_0} \right) G(\tilde{x}, \tilde{y}; \tilde{x}_v, \tilde{y}_v) \\ & + \sum_{n=1}^N \frac{Q_n}{Q_0} \frac{1}{2\pi(2 - e^{-\pi \tilde{y}_v})} \left\{ \sum_{j=1}^4 L(t_j) \right. \\ & \left. - \left( \frac{2 - e^{-\pi \tilde{y}_v}}{2} \right) \log [(1 - a_j)^2 + b_j^2] \right\} \\ L(t_j) = & 1 + e^{\pi \tilde{y}_v} \left\{ \frac{a_j}{2} \log \left[ \frac{e^{-\pi \tilde{y}_v} - a_j^2 + b_j^2}{a_j^2 + b_j^2} \right] \right. \\ & \left. + |b_j| \left[ \arctan \left( \frac{a_j - e^{-\pi \tilde{y}_v}}{|b_j|} \right) - \arctan \left( \frac{a_j}{|b_j|} \right) \right] \right\} \end{aligned}$$

$$\begin{aligned}
& + \log \left[ \frac{(1-a_j)^2 + b_j^2}{(e^{-\pi \tilde{y}_v} - a_j)^2 + b_j^2} \right] \\
& - \frac{1}{2} a_j \frac{e^{-\pi \tilde{y}_v}}{(a_j^2 + b_j^2)} \log \left[ \frac{(1 - a_j)^2 + b_j^2}{(1 - a_j e^{\pi \tilde{y}_v})^2 + (b_j e^{\pi \tilde{y}_v})^2} \right]
\end{aligned}
\tag{35}$$

$$- \frac{e^{-\pi \tilde{y}_v} |b_j|}{(a_j^2 + b_j^2)} \left\{ \arctan \left( \frac{a_j - e^{-\pi \tilde{y}_v}}{|b_j|} \right) - \arctan \left( \frac{a_j - 1}{|b_j|} \right) \right\}$$

$$a_1 = -e^{\pi \tilde{y}} \cos [\pi(\tilde{x} + \tilde{x}_n)]$$

$$b_1 = e^{\pi \tilde{y}} \sin [\pi(\tilde{x} + \tilde{x}_n)]$$

$$a_2 = e^{-\pi \tilde{y}} \cos [\pi(\tilde{x} - \tilde{x}_n)]$$

$$b_2 = e^{-\pi \tilde{y}} \sin [\pi(\tilde{x} - \tilde{x}_n)]$$

$$a_3 = -e^{-\pi \tilde{y}} \cos [\pi(\tilde{x} + \tilde{x}_n)]$$

$$b_3 = e^{-\pi \tilde{y}} \sin [\pi(\tilde{x} + \tilde{x}_n)]$$

$$a_4 = e^{\pi \tilde{y}} \cos [\pi(\tilde{x} - \tilde{x}_n)]$$

$$b_4 = e^{\pi \tilde{y}} \sin [\pi(\tilde{x} - \tilde{x}_n)]$$

## 6. THE BOTTOM MOTION

When the vertical distance above the hold bottom becomes comparable to the slot width, the flow pattern departs from that calculated in previous sections. While the length  $l$  of the slot is still long compared with the half-width  $d$ , the vertical scale is now of order  $d$  since the downward flow must terminate at the bottom. The boundary layers at the sides of each slot, which carry the ventilation air downward, must spill out into the bottom across the full width of the slot. The horizontal motion must also adjust so that it can come to rest at the bottom.

To proceed, we consider the dimensional dependent variables introduced in equation (2). Substituting these into the linearized form of equation (1) (recall that  $Re \sim 0$  (1)), the equations of motion become:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial p}{\partial x} = \mu \Delta u$$

$$\frac{\partial p}{\partial y} - \frac{\rho g}{T_0} \Theta = \mu \Delta v \tag{36}$$

$$\frac{\partial p}{\partial z} = \mu \Delta w$$

$$\frac{T_1 - T_0}{h} v = \frac{\mu}{\rho Pr} \Delta \Theta$$



The geometry is shown schematically in figure (7). Equation (36) is to be solved subject to the following boundary conditions:

$$u(x, y, \pm d) = u(x, 0, z) = 0$$

$$v(x, y, \pm d) = v(x, 0, z) = 0$$

(37)

$$w(x, y, \pm d) = w(x, 0, z) = 0$$

$$\theta(x, y, \pm d) = \theta(x, 0, z) = 0$$

Finally, for  $y \gg d$ , the solutions for  $u$ ,  $v$ ,  $w$ , and  $\theta$  must merge smoothly with those obtained in sections 2-5. This statement will be made in a more quantitative fashion below.

The solution procedure is based on explicitly recognizing the differences between the four relevant length scales in the problem. These scales are, in decreasing order of magnitude:

- 1.) The slot length  $\ell$
- 2.) The scale height for large scale motion ( $\ell \sqrt{f(\omega)}$ )
- 3.) The slot half width  $d$
- 4.) The slot wall boundary layer thickness ( $d/\omega$ )

The slot bottom region is now divided into two wall boundary layers and an interior region. In the interior region the dependent variables are expanded in an ascending series in the parameter ( $d/\ell$ ) of the form:

$$\begin{aligned}
p &= \frac{3}{2} \frac{\mu Q_0}{d^3 \sqrt{f(\omega)}} \{ \tilde{p}(\tilde{x}, 0) + \left(\frac{d}{\ell}\right)^2 p^*(\tilde{x}, Y, Z) + \dots \} \\
u &= \frac{3}{2} \frac{Q_0}{\ell d \sqrt{f(\omega)}} \{ u^*(\tilde{x}, Y, Z) + \dots \} \\
v &= \frac{3}{2} \frac{Q_0}{\ell d \sqrt{f(\omega)}} \left(\frac{d}{\ell}\right) \{ v^*(\tilde{x}, Y, Z) + \dots \} \\
w &= \frac{3}{2} \frac{Q_0}{\ell d \sqrt{f(\omega)}} \left(\frac{d}{\ell}\right) \{ w^*(\tilde{x}, Y, Z) + \dots \} \\
\Theta &= \frac{T_0}{\rho g d} \frac{3}{2} \frac{\mu Q_0}{d^3 \sqrt{f(\omega)}} \left(\frac{d}{\ell}\right)^2 \{ \Theta^*(\tilde{x}, Y, Z) + \dots \} \\
\tilde{x} &= x/\ell; \quad Y = y/d; \quad Z = z/d
\end{aligned} \tag{38}$$

Note that in equation (38);  $\tilde{p}(\tilde{x}, 0)$  is the pressure obtained from the calculation of the large scale motion in section 4. The velocity components and temperature are scaled to ensure consistency with the large scale motion and with each other. Substitution of equation (38) into equation (36) and ignoring terms of order  $(d/\ell)^2$  yields:

$$\begin{aligned}
\frac{\partial u^*}{\partial \tilde{x}} + \frac{\partial v^*}{\partial Y} + \frac{\partial w^*}{\partial Z} &= 0 \\
\frac{\partial \tilde{p}}{\partial \tilde{x}}(\tilde{x}, 0) &= \frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 u^*}{\partial Z^2} \\
\frac{\partial p^*}{\partial Y} - \Theta^* &= \frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 w^*}{\partial Z^2}
\end{aligned} \tag{39}$$

Since the driving force in equation (39),  $\frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0)$  is known, the velocity component in the direction of the slot,  $u^*$ , can be obtained separately from the other variables, as the solution of (recall the second of equation (8)):

$$\frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 u^*}{\partial Z^2} = \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0)$$

$$u^* (\tilde{x}, 0, Z) = u^* (\tilde{x}, Y, -1) = u^* (\tilde{x}, Y, +1) = 0 \quad (40)$$

$$\lim_{Y \rightarrow \infty} u^* (\tilde{x}, Y, Z) - \frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2)$$

To proceed,  $u^*$  is written as the sum of the large scale motion near the bottom plus a correction.

$$u^* = -\frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2) + \bar{u}$$

$$\frac{\partial^2 \bar{u}}{\partial Y^2} + \frac{\partial^2 \bar{u}}{\partial Z^2} = 0$$

$$\bar{u} (\tilde{x}, Y, -1) = \bar{u} (\tilde{x}, Y, +1) = 0 \quad (41)$$

$$\bar{u} (\tilde{x}, 0, Z) = \frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2)$$

$$\lim_{Y \rightarrow \infty} \bar{u} = 0$$

The correction  $\bar{u}$  can be expressed in terms of a Green's function  $G(Y, Z; Y_0, Z_0)$  in a manner analogous to that described in previous sections. The result of the calculation is:

$$\bar{u}(\tilde{x}, Y, Z) = -\frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}}(\tilde{x}, 0) \int_{-1}^1 dZ_0 (1-Z_0^2) \frac{\partial G}{\partial Y_0}(Y, Z; 0, Z_0)$$

$$G + iJ = \frac{1}{2\pi} \{ \log(\phi - \phi_0) - \log(\phi - \bar{\phi}_0) \}$$

$$\phi = \sin(\pi\lambda); \lambda = Z + iY \quad (42)$$

$$\phi_0 = \sin(\pi\lambda_0); \lambda_0 = Z_0 + iY_0$$

$$\bar{\phi}_0 = \sin(\pi\bar{\lambda}_0); \bar{\lambda}_0 = Z_0 - iY_0$$

The final expression for  $u^*$  can be rewritten in a more convenient form for computation by employing the Cauchy-Riemann equations to eliminate  $\frac{\partial G}{\partial Y_0}$ . The result is:

$$u^*(\tilde{x}, Y, Z) = -\frac{\partial \tilde{p}}{\partial \tilde{x}}(\tilde{x}, 0) \left\{ \frac{1}{2} (1-Z^2) - \int_{-1}^1 dZ_0 Z_0 J(Y, Z; 0, Z_0) \right\}$$

$$J = \frac{1}{\pi} \arctan \left\{ \frac{I(Z, Y)}{R(Z, Y) - R(Z_0, 0)} \right\}$$

$$\text{if } R(Z, Y) > R(Z_0, 0); \quad (43)$$

$$J = \frac{1}{\pi} \left\{ \pi - \arctan \left[ \frac{I(Z, Y)}{R(Z_0, 0) - R(Z, Y)} \right] \right\}$$

$$\text{if } R(Z_0, 0) > R(Z, Y).$$

The quantities  $I$  and  $R$  are given by:



$$R(Z,Y) = \sin \left( \frac{\pi}{2} Z \right) \cosh \left( \frac{\pi}{2} Y \right) \quad (44)$$

$$I(Z,Y) = \cos \left( \frac{\pi}{2} Z \right) \sinh \left( \frac{\pi}{2} Y \right)$$

Note that  $u^*$  as given by equations (43) and (44) has the form:

$$u^* = - \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) U(Y, Z) \quad (45)$$

Thus, the velocity profile at each axial station  $\tilde{x} = \text{constant}$  has the same "universal profile"  $U(Y,Z)$ . This profile is displayed in figure (8). The  $\tilde{x}$  dependence can be factored out of all the variables in equation (39); the resulting decomposition being given by:

$$\begin{aligned} v^* &= \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0) V(Y, Z) \\ w^* &= \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0) W(Y, Z) \\ \theta^* &= \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0) \Theta(Y, Z) \\ p^* &= \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0) P(Y, Z) \end{aligned} \quad (46)$$

The profile functions  $V$ ,  $W$ ,  $\Theta$ , and  $P$  satisfy:

$$\frac{\partial V}{\partial Y} + \frac{\partial W}{\partial Z} = U$$

$$\frac{\partial P}{\partial Z} = \frac{\partial^2 W}{\partial Y^2} + \frac{\partial^2 W}{\partial Z^2}$$

(47)

$$\frac{\partial P}{\partial Y} - \Theta = \frac{\partial^2 V}{\partial Y^2} + \frac{\partial^2 V}{\partial Z^2}$$

$$(\omega^4) V = \frac{\partial^2 \Theta}{\partial Y^2} + \frac{\partial^2 \Theta}{\partial Z^2}$$

In order to proceed further, it is necessary to consider the dependence of the solutions on  $\omega$ . In particular, the structure of the wall boundary layers (of thickness  $(\omega)^{-1}$  on the slot half-width scale) must be determined (see figure 7). The boundary layer structure can be found from equation (47) without loss of generality; since the  $\tilde{x}$  dependence factors out in the form given by equation (47) everywhere in the slot bottom. Symmetry considerations then permit attention to be confined to the wall layer near  $Z = -1$ , the layer near  $Z = +1$  being identical. In this region:

$$V = \omega \hat{V}(\zeta, Y)$$

$$W = \hat{W}(\zeta, Y)$$

$$\Theta = \omega^3 \hat{\Theta}(\zeta, Y) \quad (48)$$

$$P = \omega^3 \hat{P}(\zeta, Y)$$

$$\zeta = \omega(Z + 1)$$

Substitution of expressions (48) into equation (47) and keeping the leading order terms in  $\omega$  leads to the wall boundary layer equations in the form:

$$\frac{\partial \hat{V}}{\partial Y} + \frac{\partial \hat{W}}{\partial \zeta} = 0$$

$$\frac{\partial \hat{P}}{\partial \zeta} = 0$$

(49)

$$\frac{\partial \hat{P}}{\partial Y} - \hat{\Theta} = \frac{\partial^2 \hat{V}}{\partial \zeta^2}$$

$$\hat{V} = \frac{\partial^2 \hat{\Theta}}{\partial \zeta^2}$$

At the wall,  $\zeta = 0$ , the velocity components and the temperature perturbation must vanish (the latter due to the assumed equilibrium between container stacks and hold stratification). As  $\zeta \rightarrow \infty$  these solutions must match the expressions for  $V$ ,  $W$ ,  $\Theta$ , and  $P$  (which have not yet been found) in the interior of the slot bottom region. For the present, we assume only that all quantities are bounded in the interior, as  $\zeta \rightarrow \infty$ .

Equation (49) may be readily solved by noting that, from the second of these equations:

$$\hat{P} = \hat{P}(Y) \tag{50}$$

Although  $\hat{P}(Y)$  is as yet unknown,  $\hat{V}$  and  $\hat{\Theta}$  may then be found in terms of  $\hat{P}(Y)$  as:

$$\hat{\Theta} = \frac{\partial P}{\partial Y} \{1 - \exp(-\zeta/\sqrt{2}) \cos(\zeta/\sqrt{2})\} \quad (51)$$

$$\hat{V} = -\frac{\partial P}{\partial Y} \exp(-\zeta/\sqrt{2}) \cos(\zeta/\sqrt{2})$$

Note that as  $\zeta \rightarrow \infty$  (i.e. as the interior of the bottom region  $\Theta$  is approached)

$$\hat{\Theta} \rightarrow \frac{d\hat{P}}{dY}$$

$$\hat{W} \rightarrow (2)^{-1/2} \frac{d^2 \hat{P}}{2Y^2} \quad (52)$$

$$\hat{V} \rightarrow 0$$

In order for the interior functions (the solutions to equation (47)) to have proper scaling with respect to  $\omega$ , they must be consistent with equation (52) as  $Z \rightarrow \pm 1$ . This can be achieved by rescaling as follows:

$$V(Y, Z) = (\omega)^{-1} V_I(Y, Z)$$

$$\Theta(Y, Z) = (\omega)^3 \Theta_I(Y, Z) \quad (53)$$

$$P(Y, Z) = (\omega)^2 P_I(Y, Z)$$

The leading terms in the interior equations then become:



$$\frac{\partial W}{\partial Z} = U$$

$$\frac{\partial P_I}{\partial Z} = 0 \quad (54)$$

$$\frac{\partial P_I}{\partial Y} - \Theta_I = 0$$

From the second of equation (54) and equation (50):

$$P_I = \hat{P}(Y) \quad (55)$$

The last of equation (54) is now consistent with the first limit in equation (52), yielding the result:

$$\Theta_I = \frac{d\hat{P}}{dY}(Y) \quad (56)$$

Finally, the first of equation (54) yields:

$$W = \int_0^Z U dZ$$

where

$$U = \frac{1}{2} (1-Z^2) - \int_{-1}^1 dZ_o Z_o J(Y, Z; 0, Z_o) \quad (57)$$

(see equation (43)).

The transverse profile W is displayed in figure 9. Note that U is symmetric in Z, so W is anti-symmetric. The remaining unknown  $\hat{P}(Y)$  is

determined by requiring that  $W(\pm 1, Y)$  be consistent with the matching condition given the second of equation (52). Thus:

$$\frac{d^2 \hat{P}}{dY^2} = -\sqrt{2} \int_0^1 U(Z, Y) dZ \quad (58)$$

This equation can be integrated once with respect to  $Y$ , using the value  $\frac{d\hat{P}}{dY}(0) = 0$  to ensure that the vertical velocity in the wall layer vanishes at  $Y = 0$  (see equation (51)).

The most important results of this section are equations (43) and (57), which yield the profiles for the two principal velocity components in the bottom region. These profiles will now be used in the calculation of the vapor pickup in this region.

## 7. THE VAPOR PICKUP

The calculation of the vapor pickup requires a solution for the vapor concentration gradient at the bottom of the hold. In order to proceed, it is necessary to recall the spill scenario postulated in section 2. It is now further assumed that the bulk of the pickup takes place along the bottom, but outside the wall boundary layers. The concentration  $C(x, y, z)$  then obeys the equation:

$$u \frac{\partial C}{\partial X} + w \frac{\partial C}{\partial Z} = D \Delta C \quad (59)$$

Here  $D$  is the diffusivity of the spill vapor in air,  $\Delta$  is again the Laplacian operator; and  $u$  and  $w$  are the velocity components determined in the previous

section. At  $y=0$ , the concentration is assumed to be  $C_0$ , the equilibrium vapor pressure at the temperature corresponding to the hold bottom. Outside the layer, there is no vapor;  $C=0$ .

We now non-dimensionalize the velocities and coordinates as in equation (38). The concentration equation (59) then takes the form:

$$u^* \frac{\partial C}{\partial \tilde{x}} (\tilde{x}, Y, Z) + w^* \frac{\partial C}{\partial Z} (\tilde{x}, Y, Z) = \frac{1}{R_e^* S_c} \Delta_2 C$$

$$\Delta_2 C \equiv \frac{\partial^2 C}{\partial Y^2} + \frac{\partial^2 C}{\partial Z^2}$$

$$R_e^* = \frac{3Q_0}{2\ell d \sqrt{f(\omega)}} \left(\frac{d}{v}\right) \left(\frac{d}{\ell}\right)$$

(60)

$$S_c = v/D$$

Equation (60) must be solved subject to the boundary conditions:

$$C(\tilde{x}, 0, Z) = C_0$$

(61)

$$\lim_{Y \rightarrow \infty} C(\tilde{x}, Y, Z) = 0$$

The solution procedure employed is a generalization to three dimensions of that used by Lighthill [12] in obtaining his heat transfer formula. Recall that equations (45), (46) and (57) allow  $u^*$  and  $w^*$  to be expressed as:

$$u^* = - \frac{\partial \tilde{P}}{\partial \tilde{x}} (\tilde{x}, 0) \frac{\partial W}{\partial Z} (Y, Z) \quad (62)$$

$$w^* = \frac{\partial^2 \tilde{P}}{\partial \tilde{x}^2} (\tilde{x}, 0) W(Y, Z)$$

Following Lighthill, the vertical dependence of velocity profiles is approximated by a linear function.

$$W(Y, Z) \approx W_0(Z)Y, \quad W_0 \equiv \left( \frac{\partial W}{\partial Y} \right)_{Y=0} \quad (63)$$

This approximation may be justified in several ways. First, when the Schmidt number  $S_c \gg 1$ , it is rigorously true that this simplification yields the asymptotic solution for the concentration profile. Lighthill has shown that in the case of heat transfer, the approximation works quite well for Prandtl numbers of 0.7, corresponding to air. In the present application,  $S_c$  is usually in the range  $1.5 < S_c < 2$ . For this range of Schmidt numbers, the concentration field is largely controlled by the velocity profiles near the bottom. Inspection of figures (8) and (9) shows that the velocity profiles are fairly linear in this region. Finally, it should be noted that only the wall concentration gradient is required, not the whole concentration profile. Such information can be (and often is) obtained using much cruder profile information than will emerge from this calculation.

It is convenient to express the velocity components in terms of a stream function  $\psi(\tilde{x}, Z)$  defined as:

$$\psi(\tilde{x}, Z) = - \frac{\partial \tilde{P}}{\partial \tilde{x}} (\tilde{x}, 0) W_0(Z) \quad (64)$$



The velocity components are given by:

$$\begin{aligned} u^* &= Y \frac{\partial \psi}{\partial Z} ; \\ w^* &= - Y \frac{\partial \psi}{\partial x} \end{aligned} \quad (65)$$

The vertical coordinate is now rescaled as follows:

$$\lambda = (R^* S_e^*)^{1/3} Y \quad (66)$$

The concentration equation now becomes:

$$\eta \left\{ \frac{\partial \psi}{\partial Z} \frac{\partial C}{\partial \tilde{x}} - \frac{\partial \psi}{\partial \tilde{x}} \frac{\partial C}{\partial Z} \right\} = \frac{\partial^2 C}{\partial \lambda^2} \quad (67)$$

The solution of equation (67) depends crucially on the observation that curves of constant  $\psi$  represent the trace of the streamlines calculated in section 6 on the bottom. These streamlines originate in the wall layer at the side of each container stack. Let  $s$  denote distance along each streamline with the origin at the point where the streamline emerges from the wall (see figure 10). Using  $s, \psi$  as independent variables in place of  $\tilde{x}, Z$ ; equation (67) becomes:

$$\begin{aligned} q(s, \psi) \lambda \frac{\partial C}{\partial s} &= \frac{\partial^2 C}{\partial \lambda^2} \\ q^2 &= \left( \frac{\partial \psi}{\partial Z} \right)^2 + \left( \frac{\partial \psi}{\partial \tilde{x}} \right)^2 \end{aligned} \quad (68)$$

At  $s=0$ ; the ventilation air has just entered the bottom region; hence  $C=0$ . At  $\lambda=0$ ;  $C=C_0$  and  $C \rightarrow 0$  and as  $\lambda \rightarrow \infty$  from equation (61). This is a relatively straightforward problem. To proceed, we introduce a modified streamwise variable  $\xi$  defined as:

$$\xi = \int_0^s ds/q(s,\psi) \quad (69)$$

then

$$\eta \frac{\partial C}{\partial \xi} = \frac{\partial^2 C}{\partial \lambda^2} \quad (70)$$

Introducing laplace transforms with respect to  $\xi$ ; equation becomes:

$$p\lambda \bar{C} = \frac{\partial^2 \bar{C}}{\partial \lambda^2}$$

$$\bar{C} = \int_0^\infty e^{-p\xi} C(\xi, \lambda) d\xi \quad (71)$$

$$\bar{C}(\xi, 0) = \frac{C_0}{p}; \quad \bar{C} \rightarrow 0 \text{ as } \eta \rightarrow \infty$$

The solution for  $\bar{C}$  satisfying equation (71) is readily found [13] to be:

$$\bar{C} = \frac{C_0}{p} \Gamma(2/3) (3)^{2/3} Ai((p)^{1/3} \lambda) \quad (72)$$

Here  $Ai$  is the Airy function, and  $\Gamma$  the Gamma function as defined in reference [13].

Although inversion of  $\bar{C}$  to obtain the concentration profile would be a formidable undertaking, the problem becomes tractable if only the wall concentration gradients are required. The mass flux picked up at each point by the ventilation system,  $\dot{m}$ , is given by:

$$\dot{m} = -D \frac{\partial C}{\partial y} \quad (73)$$

$$= -\frac{D}{d} (R_e^* S_c)^{1/3} \frac{\partial C}{\partial \lambda}$$

From equation (72), the laplace transform  $\bar{\dot{m}}$  is readily computed as:

$$\bar{\dot{m}} = \frac{D}{P} (R_e^* S_c)^{1/3} C_o (3)^{1/3} \frac{\Gamma(2/3)}{\Gamma(1/3)} (p)^{-2/3} \quad (74)$$

Inverting equation (74) and recalling the definition of  $\xi$  from equation (69), the mass flux becomes:

$$\dot{m} = \frac{D}{d} C_o \frac{3 R_e^* S_c}{\Gamma(1/3)} \left\{ \int_0^S ds/q(s, \psi) \right\}^{-1/3} \quad (75)$$

$\Gamma(1/3) = 2.67894\dots$

Equation (75) yields the pickup at each point in a given slot. The quantity actually desired is the total mass pickup. The total mass pickup in a slot  $\dot{M}$  is given by:

$$\begin{aligned} \dot{M} &= \int_{-d}^d dz \int_0^{\ell} dx \dot{m} \\ &= 2d\ell \int_0^1 dZ \int_0^1 d\tilde{x} \dot{m}(\tilde{x}, Z) \end{aligned} \quad (76)$$

Now let  $s$  and  $n$  be coordinates along and normal to a streamline  $\psi =$  constant. Then, from equations (75) and (76):

$$\dot{M} = dD \ell C_o \frac{(3R^*S_e)_c^{1/3}}{\Gamma(1/3)} \iint ds dn \left\{ \int_0^s ds/q(s, \psi) \right\}^{-1/3} \quad (77)$$

Using the fact that  $dn = d\psi/q$ , and  $d\xi = ds/q$ , it is possible to carry out the integral along streamlines to obtain:

$$\dot{M} = \frac{2D \ell C_o (3R^*S_e)_c^{1/3}}{\Gamma(1/3)} \int_0^{\psi_M} d\psi \frac{3}{2} [\xi(\psi)]^{2/3} \quad (78)$$

$$\xi_M(\psi) = \int_0^{s_M(\psi)} ds/q$$

Here  $s_M(\psi)$  denotes integration over the entire distance along each streamline from the point it enters the bottom until the time it exits into the end void (see figure 10). Similarly,  $\psi_M$  denotes the maximum value of the stream function, so that the integration covers all streamlines originating in the wall layer.

At this point it is convenient to recapitulate the overall calculation procedure. The first step is the determination of the flow assigned to each slot and to the end void. This is given by equation (19), which yields the total flow in each slot,  $Q_n$ , as a function of the total flow drawn through the hold, the hold geometry, and the degree of stratification. The next step is the computation of the pressure gradient along the bottom of each slot

containing spill material. This pressure gradient controls the development of the spill material boundary layer, and hence the rate at which spill material is picked up by the ventilation system. The necessary result is given in equation (27). Note that this formula, in turn, requires a knowledge of the variation of the void pressure  $\tilde{p}_v$  with height at the open end of each slot in question. The void pressure at any point is given by equation (35), which requires only the information already obtained from equation (19). With the pressure gradient along the slot bottom now determined, the velocity distribution near the slot bottom are given by equations (43-46) and (57). These results are then used to get approximate simplified formulae, equations (63) and (64), which are actually used in the calculation of the rate of pickup of spill material. These latter formulae express the velocities near the bottom of each slot in terms of a "bottom stream function"  $\psi$ . Given the quantity  $\psi$ , the magnitude of the velocity gradient at each slot bottom,  $q$ , can be determined from equation (68). Finally, given  $q$  and  $\psi$ , equation (77) yields the total mass pickup in each slot  $\dot{M}$ . These results, summed over all the slots containing spill material, yield the total mass per unit time extracted from the hold by the ventilation system. The computer program which executes these calculations is of necessity quite elaborate. The following sections describe the overall program layout, the principal subroutines, sample results and a complete listing.



## 8. NUMERICAL PROGRAMS

Two main programs were written. The larger one carries out the numerical calculations of the containership hold ventilation model; while the other plots selected pressures and streamlines. Although the plot program uses CALCOMP emulation subroutines, the program is sufficiently specialized to our computer that it would have limited interest. It will not be described.

### 8.1 Main Numerical Program

The main numerical program controls the entire calculation, i.e., all subroutines are called from the main program. There are eleven of these. In addition, there are two external function routines. These are called from subroutines. A simple block diagram of the program is shown in figure 11.

The first two subroutines, INTEG1 and INTEG2, carry out numerical integrations related to the flow at the bottom of a slot. In the dimensionless variables used, these are geometry independent. PRINT then tabulates the geometry independent dimensionless slot bottom quantities. Since they do not depend on input data they are carried out once and the results saved for use in all variable geometries to be calculated.

The program is arranged to calculate multiple geometric or thermal cases. The number of these is read (NGEOMS) and a loop entered between CALL INPUT and the end of the main program. INPUT reads, from the input file or device, logical unit 5, the geometric and temperature values to be used. At this point the main program performs two scaling operations, one for the main

transverse space (which will be referred to as the "main void" or simply the "void") and the second for the gaps extending fore and aft between stacks of containers (referred to as "intercontainer slots" or simply "slots"). These operations correspond to the quantities  $\omega$  and  $f(\omega)$ , defined in equations (6) and (10). The void and the intercontainer slot volumes are assumed to be the only unoccupied space in the hold. For ships with wing tanks, the main void is the volume on the framed side of the transverse bulkhead between the bulkhead and the container stacks. Where there are no wing tanks, the main void is increased in length to account for the volumes between the outermost container stack and the side of the ship. The scaled lengths of the void and slots are then compared to their respective widths to see if the assumptions of the model are satisfied, namely that the scaled widths are less than their lengths. Actually, the widths should be much less than the lengths. If either of these scaled lengths is less than the respective widths, program execution stops with an appropriate message.

The air issuing from the slots into the main void could be a problem to the model if the flow were strong enough to have a jet-like character. In addition, if the slots were spaced close enough together, after scaling, compared to the width of the void they might interact violating another assumption of the model--that the slots are widely spaced. For some actual ship hold geometries this condition may, in fact, be violated. However, the void is not a simple, smooth sided space as assumed by the model but, rather, a complex of interconnected volumes formed by the framing of the bulkhead. It is further broken up by supports for the containers. The structure provides considerable surface for heat exchange and can break up and separate any jets. For practical purposes there seems no way to treat the void correctly

in any detail. Accordingly, it was decided to treat it as a simple smooth space as per this model, recognizing that this was questionable. Having made this decision, the scaled slot spacing to void width ratio is computed and printed. If this ratio is not small a warning is also printed.

If the transverse location of the suction aligns with one of the slots there will be numerical problems. Should this occur, the suction is arbitrarily moved away from the slot  $1/2\%$  of the void length. This is a distance less than the resolution scale of the overall calculation. Another check looks at the location of the (single) suction to see if it is very near the tank top,  $Y=0$ . The calculation assumed it is not. If it is, it is arbitrarily moved up 5 cm. Next, the slots numbers, for the slots furthest and closest to the suction, are determined for later use in plotting pressures and streamlines. It turns out that, even for very small stable stratification temperature differences, the differences in the flow in the several slots is very small, hence only selected results need be displayed to adequately show the flows.

Having completed these housekeeping details, the calculation proper begins. The main calculation is a large loop, passing once around for each slot. Within the loop the slot bottom flow is calculated,  $SLOT1$ , and streamlines traced,  $STRM1$ . The mass pick-up is then obtained for the separate stream tubes by integrating along the streamlines,  $PICUP1$ . Finally, the total mass evaporated from the slot is obtained by integration over all the stream tubes, also  $PICUP1$ . This is repeated for each slot and the total mass evaporated obtained by summing the contributions from each slot. In tracing the streamlines, a matrix,  $ZPSI$ , giving the transverse location,  $z(x)$ , for



various constant values of slot bottom stream function is formed. This is used in calculating the stream tube integrals and is unique to any given slot. Since the matrix is over-written with each pass through the loop, the ZPSI matrix for two slots--the one closest to the suction and the one furthest from it--are saved as a convenience for later plotting. Upon completion of this calculation for all the slots, results are printed. PRNT1 tabulates the dimensionless slot velocity and stream functions. The axial velocity near the bottom of the slot, USLOT (u of equation (43)), is a function of axial distance along the slot and differs for each slot. This is the axial velocity in the slot just above the boundary layer at the slot bottom. The slot bottom boundary layer velocity approaches USLOT asymptotically with height. The slot bottom stream function defines the track of the air as it passes over and evaporates the spilled liquid assumed to be spread over the hold bottom. Stream function values are tabulated for each slot--the value of the stream function, PSI, for fixed locations along the length of the slot (rows) and fixed locations across the width of the slot (columns). Next the dimensionless mass pick-up for each slot is printed together with the corresponding dimensionless slot location.

The intent in developing this program was to be able to apply the results of the calculation to specific chemicals. Calls are made to INPUT1 where vapor pressure, temperature and diffusivity data are read for the number of chemicals specified in INPUT and NCHEMS. The total mass pick-up, in dimensional form, is computed for the hold ventilation rates read by INPUT2. Note that the mass pick-up varies in an almost trivial way with ventilation rate, the 1/3rd power, so that an eight fold increase in ventilation doubles the mass pick-up. The vapor concentration in the exhaust air is also computed for

easy comparison with lean limit flammability data. Mass pick-up results are printed by the main program. Results expressed in air changes per hour are based on volumes read by INPUT.

Finally a call to PLOT causes the slot pressure at the slot-void intersection to be computed and stored for later use. Pressure is only computed for the slots closest to and furthest from the suction.

## 8.2 Subroutines

### INTEG1

As already mentioned, in the dimensionless variables, the integral which defines the velocity in the volume between the slot bottom and approximately one slot width up from the bottom is independent of the slot geometry and degree of temperature stratification. Thus, the integral can be carried out prior to inputting specific geometric or thermal details. This is done so that, should it prove desirable, multiple geometries can be calculated by looping to INPUT thus avoiding the necessity of recomputing these integrals. The integral calculated, using the trapezoidal method, is the function  $U(Y,Z)$  given by equations (43) and (45). It is the profile function for velocity along the direction of the slot axis. It has already been shown in figure 8. The result is symmetric with respect to the slot centerline,  $Z=0$ , so only positive values are tabulated. However, positive and negative values are needed in the integrand. Also needed is  $U_0$ , the partial derivative of  $U$  with respect to  $Y$  at  $Y=0$ ;  $W_0$  defined in equation (63). The recipe for finding it includes equation (57). This is obtained by calculating  $U$  for  $Y=0.05$ ,



subtracting the value of UB at  $Y=0$ , which is 0, and multiplying the result by 20. Figure 12 shows UB for  $Z=0$  as a function of  $Y$ . It is seen to be quite smooth indicating that this approximation should be quite good. Examination of figure 8 shows that this is also true for other values of  $Z$ .

## INTEG2

INTEG2 forms the indefinite integrals with respect to  $Z$  of the quantity UB which yields  $W$ , equation (57) and of  $UB_0$  which yields  $W_0$  again using the trapezodial method.  $W$  is shown in figure 9.

## PRINT

This is a fairly straightforward tabulation.

## INPUT

For each geometry, temperature difference (stratification) data is read. Then hold geometry, as reflected by the main void and slot geometries, is read. Several consistency checks are made: the number of slots must be no more than 11 (dimension statement and format limit) and the number of  $x$  values along the slot,  $NXSLOT$ , for which values will be computed must not exceed 30 (dimension statement limit). Also the spacing between slots times the number of slots must not exceed the length given for the main void. Failure of any of these tests results in termination of execution with an appropriate message printed. The slot-void intersection locations are calculated placing the slots symmetrically about the centerline of the void. The suction location is then read.

## SLOT1

SLOT1 is a very short, simple subroutine but, through its use of the external function GRAD, which in turn employs the external function PRESS, involves a fairly complex program structure. The axial flow in a slot depends on the axial pressure gradient. SLOT1 determines the characteristic magnitude of the velocity USLOT, which is the same as  $\frac{\partial \tilde{p}}{\partial \tilde{x}}$ , near, but not quite at the slot bottom, the first term on the right of equation (45). This term is determined by equation (27). The boundary layer-like analysis of the local flow at the very bottom of the slot detailed in INTEG1 and INTEG2 is scaled to approach asymptotically the velocity USLOT as height increases away from the slot bottom.

## GRAD

Subroutine GRAD carries out the integral, equation (27), which gives the pressure gradient just above the slot bottom,  $\partial \tilde{p} / \partial \tilde{x}(\tilde{x}, 0)$ , for each slot (needed by subroutine SLOT1 as discussed above). This integral requires the vertical pressure gradient in the end void at the location of the slot, for each slot. This is found by a call to subroutine PRESS. There are two noteworthy aspects of this calculation:

- (1) The integrand of the integral carried out in GRAD has an integrable singularity for  $x = -1/2$  (the slot void intersection) and  $y=0$ . Rather than carry out the rather messy algebra to integrate this formally and provide a program option

to use the alternative algebra, use was made of the fact that the result is smooth as  $x = -1/2$  is approached. Numerical experiments for a series of values of  $x$  approaching  $-1/2$  showed that using  $x = -0.498$  gave a result very close to the extrapolated value without encountering numerical problems.  $x = -0.499$  gave a value fairly close to the extrapolated one but was suggestive of an approaching numerical problem, see figure 13.

- (2) The integral is over an infinite range. The infinite integral is completed by adding an analytically determined piece for argument three to infinity to the trapezoidal rule computation from zero to three.

## PRESS

The function PRESS is called from GRAD (and also from PLOT). It computes the pressure at the intersection of the slot at transverse location  $XS(N)$  with the main void using equation (35). This pressure depends on the flows from all the other slots.

The calculation involves two pairs of two terms each and, as will be discussed later, has some numerical problems since these terms involve small differences of not very small terms. These problems appear to be large enough to require the use of double precision on 32 bit computers. Figure 14 shows the result of calculating pressure in single precision. A double precision version of PRESS produced smooth plots, compare figure 14 with 20a. Numerical values of the mass pick-up were about 4% lower when using the double precision

pressure routine as compared to single precision. Subroutines GRAD and PRESS were originally written by Dr. D. Corley of Montgomery College and NBS.

#### STRM1

The value of the stream function in the Nth slot at a point X(I) axially along the slot length and z(k) transverse to the slot center line is given by (see equation (64)):

$$\text{PSI (I,K,N)} = \text{USLOT (I,N)} * \text{WO(K)}$$

where, as already discussed, USLOT is the characteristic velocity magnitude at this axial position in this slot as tabulated in SLOTL and WO is the indefinite z integral determined in INTEG2, of UBO, the gradient of the slot bottom velocity determined in INTEG1. The task of STRM1 is to produce, from values of the stream function at fixed geometric points, a table of coordinate pairs (x,z) which correspond to fixed values of stream function. Thus, it is rather analogous to a contour plot routine. The routine chooses an x from the equally spaced ones for which USLOT and WO are known. It determines the PSI value at this x and at the slot edge, z=1. Since flow descends along the slot walls and flows out onto the slot bottom, streamlines originate at the slot edge. The streamline originating at this x is then followed toward x = -1/2. At each fixed x between the initial one and the far end of the streamline a z is determined, by linear interpolation between the fixed z's for which WO is available, where the required stream function value is found. The result is a table of z(x) for fixed PSI, ZPSI. Most streamlines terminate at z = -1/2 with a z between 0 and 1. However, especially for slots near the suction and



suctions raised above the slot bottom, not all the flow goes directly out the end of the slot. Some of it may return to the slot side wall and flow up the wall to near the height of the suction where it finally leaves the slot. Streamlines for this flow are shown schematically in figure 10. This flow behavior is associated with a maximum in PSI for an  $x$  greater than  $-1/2$ . To identify the location of the end of a streamline it is useful to record the  $x$  location of its end, either  $-1/2$  or the  $x$  along the slot sidewall to the left of the maximum PSI where the required stream function value occurs. This is obtained by linear interpolation and recorded in XPSI(N). The matrix of values of ZPSI is returned to the main program and passed forward to PICUPI but is not retained as successive slots are treated.

#### PICUPI

The mass evaporated from the spill pool at the bottom depends on the velocity and path over the pool. The pick-up integral is given by equation (77). The limits of the integral are set by the extent of the spill. It has been assumed that the spill covers the entire hold bottom so the limits have been made on the wall where the flow enters the slot bottom and either the slot-void junction or the wall, if the flow returns there as described above. It would have been a simple extension of the program to input the extent of the spill pool, presumably less than the full length of the slots and different for each slot, but this seemed to offer little advantage since there is no information on the expected size or extent of a spill. As is done throughout the program, the trapezodial algorithm is used for the integration. Once the separate stream tube integrals have been formed the total mass pick-up for the slot is formed by integrating over the stream tubes.



## PRINT1

After all the slot quantities have been calculated the results are tabulated. The values of USLOT are printed in columns for each slot with rows corresponding to axial position X, along the slots. The columns are headed by the dimensionless slot location. The stream function is then tabulated for each slot with columns giving the transverse, Z, location and rows the axial position, X. In this case, slot location is given in dimensional units. This is followed by a short table pairing the dimensionless slot location with the total, dimensionless pick-up for that slot.

## INPUT1

In INPUT the counter NCHEMS was set. The main program now loops through INPUT1 reading chemical data for as many materials as requested by NCHEMS. The chemical data entered is the mass diffusivity and partial pressure data using the "Antoine Formula" [14]. The data is then corrected for the case temperature to give the saturation concentration and corrected diffusivity. For each chemical, several flows can be used. The effect of flow is very simple but this feature was included as a convenience. The number of flows to be considered for each chemical is read, NFLOWS.

## INPUT2

This simply reads the flow and returns. It is called as many times as requested by NFLOWS.

## P PLOT

The pressure at the slot-void intersection for the same pair of slots for which streamline data was saved in STRM1 is now calculated using the external function PRESS. This is done separately rather than saving values computed during the slot calculation to provide some additional flexibility in the range of values computed. The cost in computing time is not great.

### 8.3 Input Data

A sample input data file is given in appendix 1. The example is for a single case with a  $\Delta T$  of  $0.1^{\circ}\text{C}$ . The length of the main void (in this case the width of the hold plus twice the container length to simulate a ship without wing tanks) is 51 m, its width (fore and aft dimension) is 0.8 m and its height 20 m. The intercontainer slots are 12 m long (fore and aft), 0.1 m wide spaced 2.46 m along the length of the main void. Since the slots are the same height as the main void their height need not be input. Twenty points are calculated along the length of the slots and there are 11 slots. The suction is placed at a nominal height = 0.6 m and transverse location relative to the center line of the main void of 0.0. The hold empty volume is  $2407 \text{ m}^3$  and the void volume is  $1920 \text{ m}^3$ . One chemical is considered. The caption is for this chemical; the caption is limited to one line of 80 characters, maximum. Chemical data entered is: ,

Mass diffusivity of spill vapor at  $0^{\circ}\text{C}$   $\text{cm}^2/\text{sec}$

Molecular weight of spill chemical

Material constant, B of Antoine's formula,  $^{\circ}\text{K}$

Temperature at which spill chemical has a vapor pressure of 1 atm  $^{\circ}\text{C}$

Reference temperature, C of Antoine's formula,  $^{\circ}\text{K}$

Ambient temperature at spill liquid,  $^{\circ}\text{C}$

One flow is considered and the flow is  $1.0 \text{ m}^3/\text{sec}$ . The result of executing the program (in double precision) with this input is reproduced in appendix 2.

## 9. NUMERICAL RESULTS

The purpose of this study was to predict the mass evaporation rate for a hazardous liquid spill in a containership hold. Since no information was available about the extent of such a spill, it was assumed that the liquid would spread uniformly over the bottom of the hold (tank top). In practice, there is almost always some trim to the ship so that liquid would tend to drain to the aft end of the hold. A low point sump could collect some of the liquid which might be advantageously pumped to a safe place thus reducing the amount of liquid that would have to be removed by the rather slow evaporation process. Rolling of the ship would tend to spread the spill across the entire width of the hold. As discussed in the section of this report describing the numerical programs, the spill was assumed to extend fore and aft along the entire length of the intercontainer slots and athwart ships across all the slots. However, no evaporation was computed for the main void comprising the transverse space between the bulkhead and the end of the container stacks. Unless otherwise noted the calculations were done for a hold containing twelve

stacks of 12 m (40 foot) long containers and with eleven intercontainer slots 0.1 m wide. The container width was 2.36 m, giving slot spacing of 2.46 m. The air temperature near the bottom of the hold was taken as 10°C. Dimensional mass evaporation rates are based on vapor pressure and diffusivity data for heptane. Calculations for numerous other fuels have been made by Sealand Corp. (using a slightly less general model) and are reported elsewhere [1].

Calculations were made for various locations of a single suction pipe, for several air flow rates and several stable stratification temperatures. The effect of varying the height of the suction above the tank top is shown in figure 15 for a suction on the centerline of an idealized ship. Raising the suction from .05 m above the tank top to 1.5 meters is seen to decrease the evaporation rate by a factor of 3-1/4 for a stable stratification of 0.1°C over the hold height of 20 m. Since the evaporation rate varies as flow to the third power, to remove liquid with the suction at 1.5 meters at the same rate as with it at .05 m the flow would have to be somewhat more than 34 times as great for the 1.5 meter height (3.25 cubed). For a 1°C stable stratification this effect of suction height is seen, from figure 17, to be very much more pronounced.

Moving the suction laterally at constant height has comparatively little effect. This is illustrated in table 2 which lists the dimensionless mass pick-up for two suction locations, one on the centerline and the other near one side of the ship. Figure 16 presents the same information graphically. However, since this calculation fails to account for the interference to transverse flow occasioned by the vertical framing of the bulkhead, these results should be viewed with caution. Figure 17-a shows the calculated



pressure at the open ends of a pair of slots, one on the hold centerline (solid line), the other the last slot outboard (dots). Pressures for two suction heights are shown, .05 m, figure 17-a and 0.6 m, figure 17-b. Note that, except for a region of about 0.2 dimensionless units around the height of the suction, the pressures are essentially the same for the two slot locations at a given suction height. Since the slot flow is determined primarily by the gradient of the pressure at  $y=0$ , little difference in the slot flows should be expected. This is reflected in the data presented in table 2. Note also the effect on the pressures below the suction of raising it, i.e., compare, in figures 17-a and 17-b, the pressure behavior below the pressure "spike". In figure 17-b, the pressure gradient is small between the tank top,  $y=0$ , and a dimensionless height of about 0.1 (dimensional height 0.2 m). The very small pressure gradient at  $y=0$  results in little flow adjacent to the tank top and little scavenging of the flammable vapors. This accounts for the behavior shown in figure 15 of mass removal rate with suction height.

Streamlines corresponding to the two sets of paired pressure distributions, figure 17a and 17b, are shown in figures 18-a,b and figures 19-a,b. In these, the transverse scale has been expanded about 100 times relative to the longitudinal scale. The drawings should be very attenuated in width to properly represent the geometry but, if so presented, would be unreadable. The first pair, figure 18, show the streamlines for the boundary layer flow at the bottom of the slots for the suction only .05 m above the tank top. A thin layer of gas flows down the sides of the containers and spreads out over the slot bottom--streamlines originating at the sides. It turns and flows along the slot bottom toward the open end of the slot. For



the slot closest to the suction the streamlines are strongly bunched in the center of the slot. For the slot farthest away from the suction the behavior is similar but the bunching of the streamlines near the centerline of the slot is less pronounced. As the suction is raised there is quite a noticeable change in the flow which becomes more marked as the suction is raised. This change is seen by comparing figures 18-a and 19-a. With the suction raised, not all the flow leaves the slot along its bottom surface. Some returns to the container sides and flows up, turning toward the main void as it approaches the height of the suction. By the same score, not all the flow descends in the thermal boundary layer next to the container sides to the slot bottom although it does toward the rear of the slot. Some of the flow near the opening into the void turns as it approaches the height of the suction and exits directly. This flow is shown schematically in figure 10. Note that flow descending all the way to the tank top has actually been over cooled. In the stably stratified situation pertaining, it must be warmed again in order to rise to the height of the suction. To gain heat it must pass close to either the walls of the main void or of the slot. Obviously, for the suction raised well above the tank top, some of the air finds it easier to seek the slot side wall rather than the main void walls. This flow behavior was found through the numerical calculation. Although it is completely plausible, it was not anticipated. As the suction is further raised the flow along the slot bottom becomes still weaker and the tendency to return to the wall decreases. It has almost completely disappeared with the suction at 1 m, figures 20a, b, and c.

The effect of increasing the stable thermal stratification is seen by comparing figures 17-a and 21. Note the different ordinate scales of the

pressure plots. In figures 17-a the temperature difference over the 20 m hold height is  $0.1^{\circ}\text{C}$  while it is  $1.0^{\circ}\text{C}$  in figure 21. The dimensional suction heights are the same but, due to the greater thermal stratification, the dimensionless height at  $\Delta T = 1.0^{\circ}\text{C}$  is greater. In general, the effect of increasing  $\Delta T$  is to compress the vertical scale of the flow. With a higher  $\Delta T$  the same vertical suction height appears to the flow as further from the tank top.

Increasing the stable temperature stratification accentuates the flow effects as shown in figures 18, 19, and 20. The flow in the slot closest to the suction bunches strongly but then spreads rapidly as the mouth of the slot is approached, figure 21-b. Even with this low suction location some flow, driven by the stronger stratification, returns to the wall. The flow in the slot furthest from the suction is less strongly affected, figure 21-c.

The main computed results for a given hold configuration and temperature stratification are expressed in dimensionless form for a nominal temperature of  $10^{\circ}\text{C}$ . To obtain dimensional output the ventilation flow and spill liquid partial pressure and diffusivity are needed. Some vapor pressure data as a function of temperature can be found in the literature [2] and, typically, the log of the vapor pressure is nearly linear with  $1/T$  as shown for heptane in figure 2. Although the theory for vapor pressure is very well developed [15], a much simpler semi-empirical approach, Antoine's formula, is found in Hirata, Oke and Nagahame [14]:

$$\log p = A - B/(C + T)$$

where  $p$  is the partial pressure,  $T$  temperature and  $A$ ,  $B$ ,  $C$  constants unique to the particular chemical. Further, since Hirata et al give values for these constants for a large number of chemicals their approach was used. Diffusivity data was corrected for temperature using the empirical relation given in [16].

It is clear from figure 2 that the equilibrium vapor concentration is a strong function of temperature. The numerical calculation obtains the concentration for the input value of slot bottom temperature. However, the flow, which depends strongly on the differential stratification temperature, but only weakly on average ambient temperature, is computed using a nominal ambient.

## 10. EXPERIMENTAL PROGRAM

An approximately 1/12 scale model of a much simplified containership hold was built. It consisted of a box with inside dimensions 1.22 m long x 2.66 m wide x 1.68 m high built of 0.65 cm fir plywood and 0.6 mm galvanized steel. To simulate the cooling effect of seawater on the hull, the bottom and lower 74 cm of the two ends were steel, maintained at constant temperature by circulating temperature controlled water through copper tubes soldered to the steel. The remainder of the apparatus was of wood, and allowed to seek room temperature. The apparatus was in a large temperature controlled room where typically the temperature varied between 18 and 25°C with an average value of 23°C during the course of a day. Inside this "hold" were three plywood boxes 1.51 m high x 1.02 m long. The center box was 0.81 m wide and the two outer boxes 0.61 m wide. These simulated stacks of containers. These three boxes

were positioned to give two slots 4 cm wide between them and 2 cm wide slots between them and the sides of the hold. All three were centered between the long sides of the hold leaving two transverse voids 10 cm wide (fore and aft). All the plywood surfaces were coated with epoxy base paint to prevent take-up of the spill vapors. A simplified cross section of the apparatus is shown in figure 22.

The flammable spill was represented by a shallow pan filled with an ethyl alcohol-water mixture. The pan was 1.16 x 2.39 x 0.025 m and held about 40 liters of mixture. The pan was placed in the "hold" and the simulated container stacks set in on pads 0.031 m high to allow the liquid to pass freely under them. The choice of a water alcohol mixture as the spill liquid was unfortunate. It was made for safety reasons. The flammable gas detector to be used could detect the alcohol vapors at concentrations well below their flammable limit and mixtures and temperatures were chosen so that only nonflammable mixtures would exist. The mixtures themselves were too dilute to support combustion. However, the concentration of the mixture was difficult to control and changed substantially during the course of a test. Thus, there was constant uncertainty about the equilibrium vapor pressure of the spill liquid.

Reducing the physical scale requires that the initial temperature difference be increased if similar flow conditions are to prevail. The dimensionless Grashof Number,  $GR = (gd^3/\nu^2)(\Delta T/T_o)(d/h)Pr$ , must be kept constant. With a 1/12 reduction in physical size the ratio  $d/h$  was increased but, in the model, the temperature difference top to bottom for similar stable stratification should be increased by a factor of 90. In practice a tempera-



ture difference of about  $15^{\circ}\text{C}$  could be achieved, equivalent to a full-scale temperature difference,  $\Delta T$ , of only  $15/90 = 0.17^{\circ}\text{C}$ . Calculations in the previous section were for  $\Delta T$ 's of 0.1 and  $1.0^{\circ}\text{C}$ . The stable situations tested are for weak stratification compared to full scale. For the unstable case, model temperature difference of only  $5^{\circ}\text{C}$  was achieved. Thus the full scale instability simulated was quite weak.

Due to the limited budget and time, no air flow measurements inside the "hold" were attempted so it was never established if the actual flows resembled those predicted by the calculations nor if there were significant circulating flows, as might arise from a transverse temperature gradient. Some tests were run in the configuration shown in figure 22 and some with the inlet and exhaust connections reversed. For all tests the cooling water was turned on and adjusted to the test conditions the day before the spill liquid was to be loaded and data taken.

Results for a stably stratified condition are shown in figure 23 for several air change rates. Note, however that, again a scaling factor enters, model air changes per hour are not the same as full-scale. The behavior during the first 15-30 minutes is erratic because of the transients associated with loading the liquid in the pan, achieving steady liquid temperature and ventilation conditions. The qualitative trend after 30 minutes, for both suction locations, is to reduce the combustible vapor concentration in the exhaust as air flow is increased. With the exhaust at the bottom, significantly more vapor is removed than with it at the top for the same air change rate.



When the behavior with a stable temperature gradient is compared to that with an unstable gradient, it is necessary to recall that, in this apparatus, the upper portion was always nominally at room temperature. When a stable temperature gradient was called for, the lower portion and the liquid pan were cooled; when an unstable gradient was desired they were warmed. Thus, with the same spill liquid, the equilibrium vapor concentration in the stable case (cool liquid) was considerably less than for the unstable case (warm liquid). At zero air changes per hour a survey of vapor concentration versus height showed little variation. At 1 air change per hour with a bottom exhaust for the unstable case the vapor concentration, except very close to the surface of the pan, was quite uniform and about 40% of its equilibrium value. For the stably stratified case the vapor concentration decreased near the pan more slowly with height than in the unstable case but leveled out at about 30% of its equilibrium value about 10 cm above the bottom and decreased slowly with height above that, figure 24. Shifting the exhaust from the center to one end had no effect to the accuracy of these tests. The behavior in the stably stratified case suggest that a significant secondary mixing flow was present, but that a mild degree of stability was achieved.

Overall the experimental results were ambiguous to mildly encouraging. They also illustrate the inadvisability of conducting convection experiments hastily and with a tight budget. The experimental apparatus was built by Mr. W. Bailey and the data taken by Mr. S. Steel, both of NBS.

## 11. CONCLUSIONS

One of the more interesting aspects of this study of a significant hazard to shipping was the almost total lack of previous scientific research at the time the initial decision of the International Maritime Consultative Organization relative to containership ventilation was made. Our limited study revealed many unanswered questions about fluid flow and heat and mass transfer in the context of maritime safety. It shed some light on one particular situation -- the ventilation of a stably stratified containership hold. Many assumptions had to be made -- when a surface temperature was needed, we assumed it was known, when geometric simplifications had to be made, it was assumed that associated complicated flow phenomena were not present. Despite these simplifications and idealizations, the work reported here is, to the best of our knowledge, the only analysis in existence that attempts to study the efficiency of ventilation in a realistic hold geometry and thermal environment.

Although much more detailed research should be done on a variety of specific points, we believe that some important conclusions can be drawn from our study and that these conclusions will stand the test of time.

- (1) In a stably stratified containership hold, almost all the extracting capability of a ventilation system will be concentrated at the vertical level of the suction.
- (2) In order to extract any significant amount of spilled material, it is essential to place the suction as close to the hold bottom as is feasible.

- (3) With few exceptions, the natural tendency of vapors from spilled liquids will be to concentrate near the hold bottom. Therefore it is not efficient to try to design the ventilation system so as to mix the gas throughout the hold.
- (4) Ventilation expressed simply as air changes per hour (for some arbitrary hold loading condition -- empty or full) is a poor measure of performance. The performance will be sensitive to the thermal environment, degree of stratification and spacing between containers.
- (5) The lack of the ability to analyze the thermal environment of a containership hold is a major impediment to systematic study of hold ventilation. There is important need for research in this area.

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- [16] Eckart, H.R.G., Introduction to Heat and Mass Transfer, McGraw-Hill, New York, 1963.



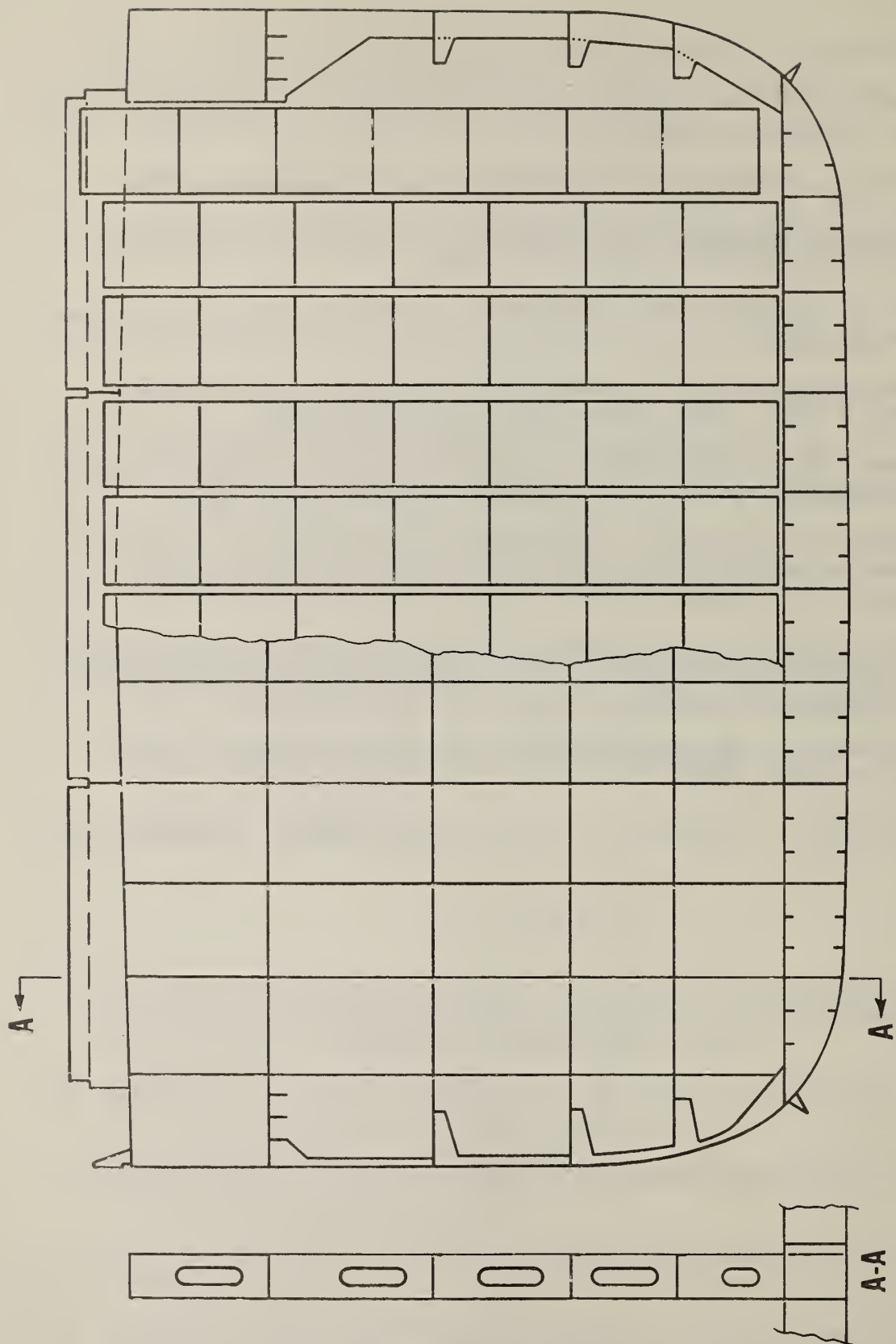


Figure 1. Cross section of a typical containership near its mid section. To the right is shown the container stacking and to the left the bulkhead framing



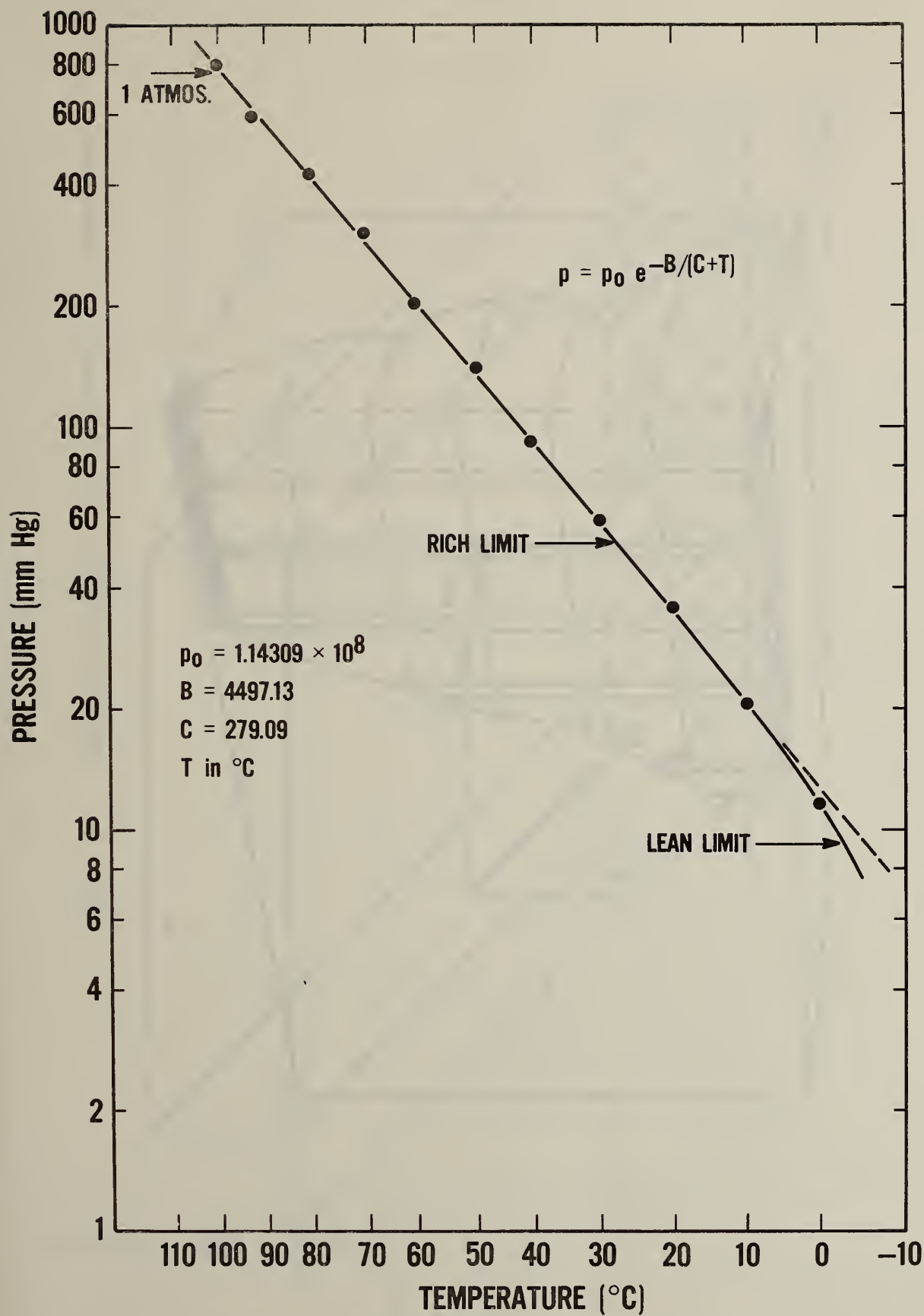


Figure 2. Vapor pressure versus temperature for heptane.  
Rich and lean limits are for an air environment

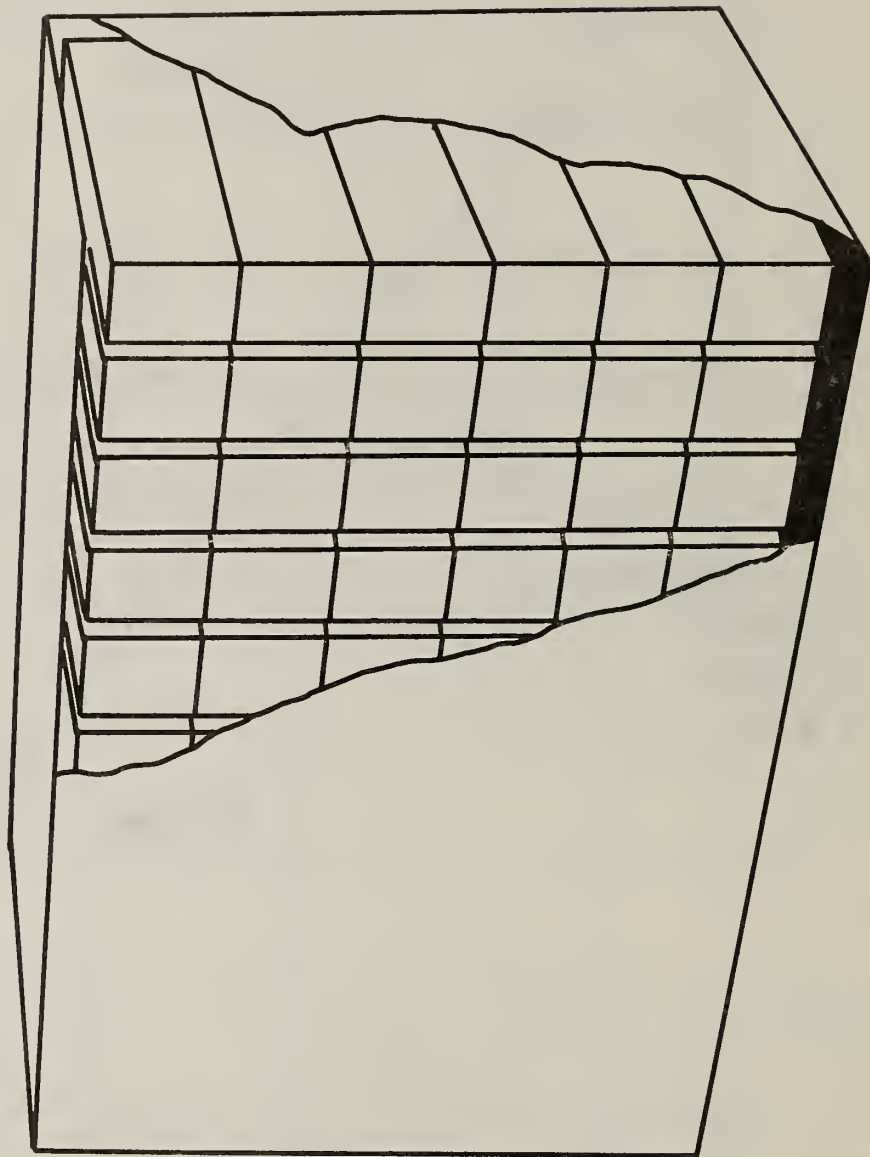


Figure 3. Idealized containership hold loaded with containers

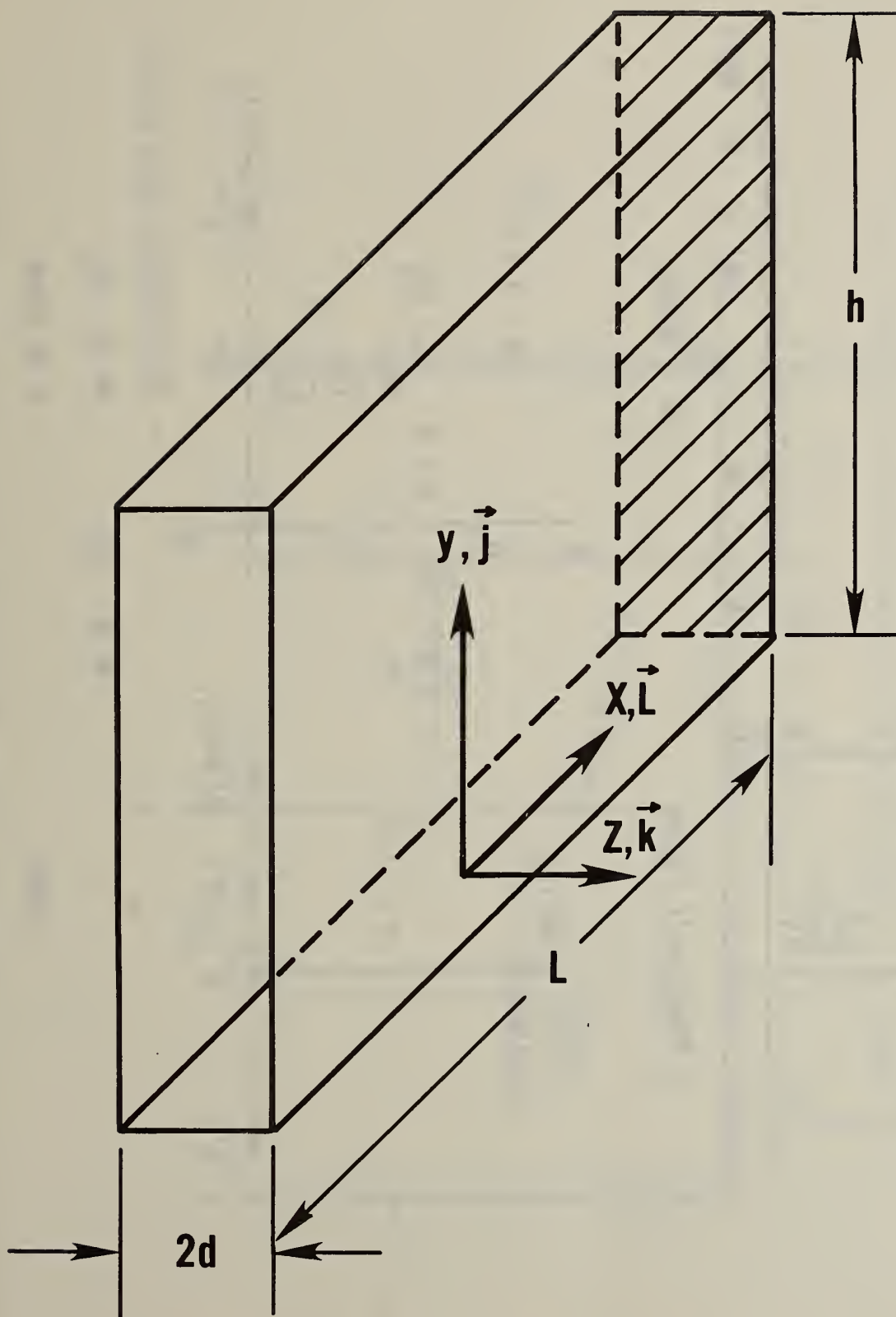
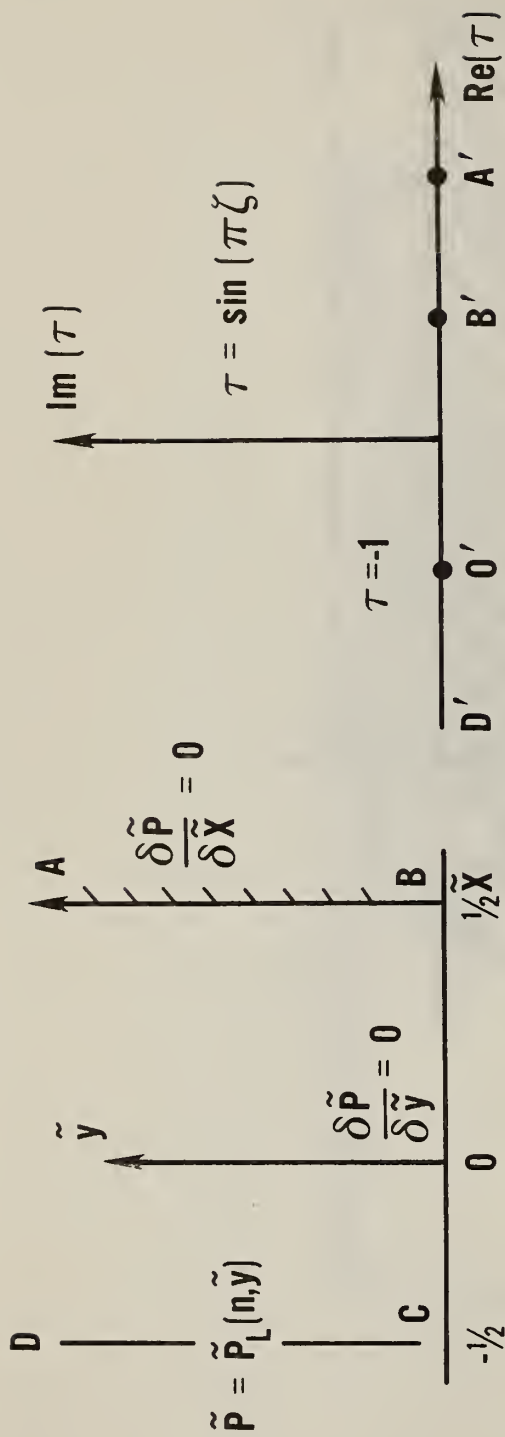
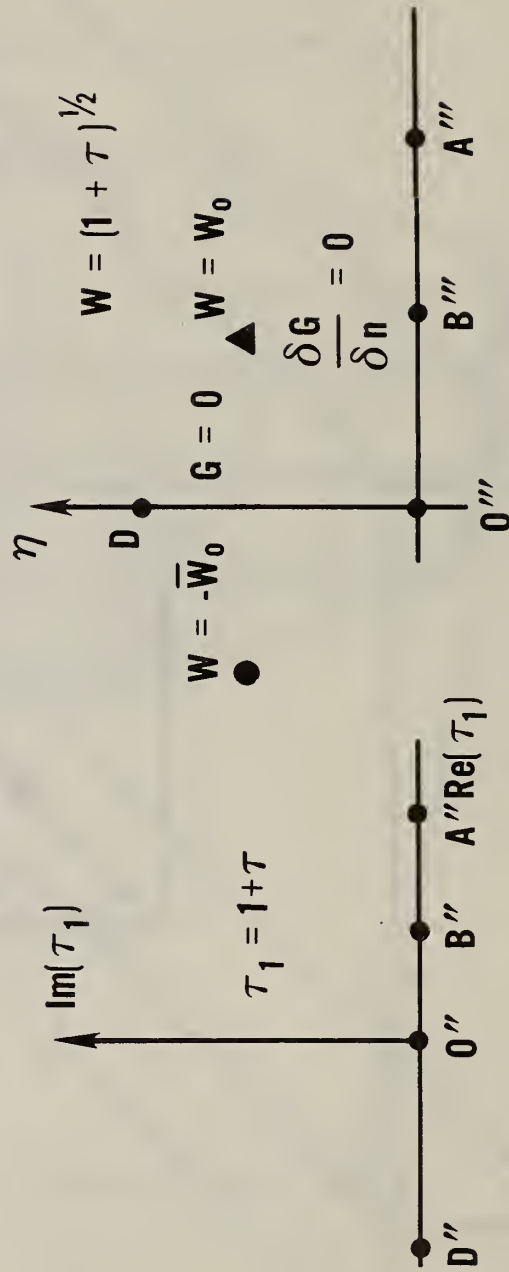


Figure 4. Geometry of the space between two stacks of containers (inter-container slot)



b.  $\tau$  plane



●  $W = -W_0$     ▲  $W = \bar{W}_0$

d.  $W$  plane

Figure 5. Conformal mappings used to obtain the Greens function,  $G$ , in equation 24



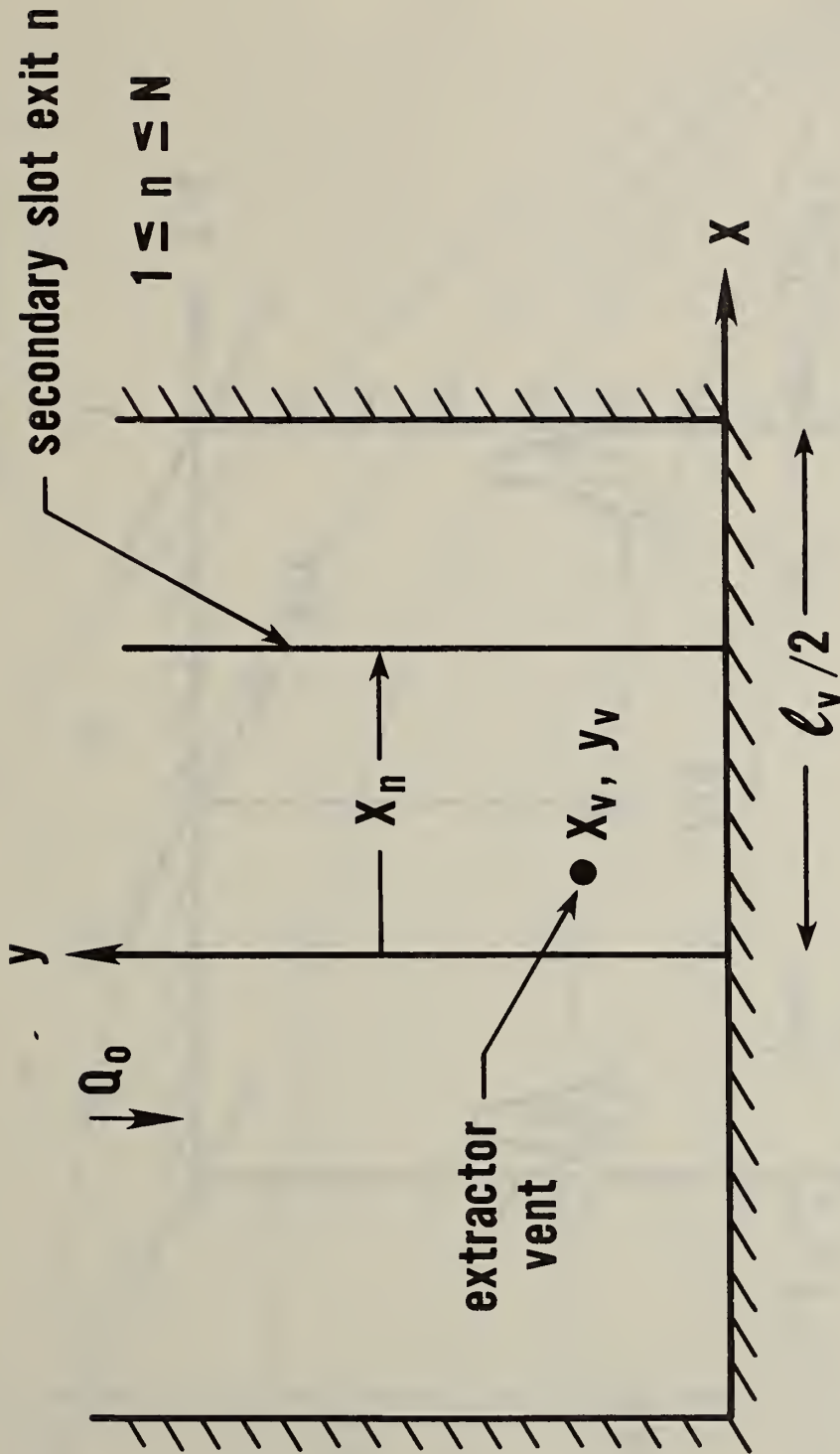


Figure 6. Plan view to the end void showing the location of the forced ventilation extraction point (suction). Ventilation flow enters from the top of the void and from the intercontainer slots (one of  $N$  slots indicated by a vertical line)

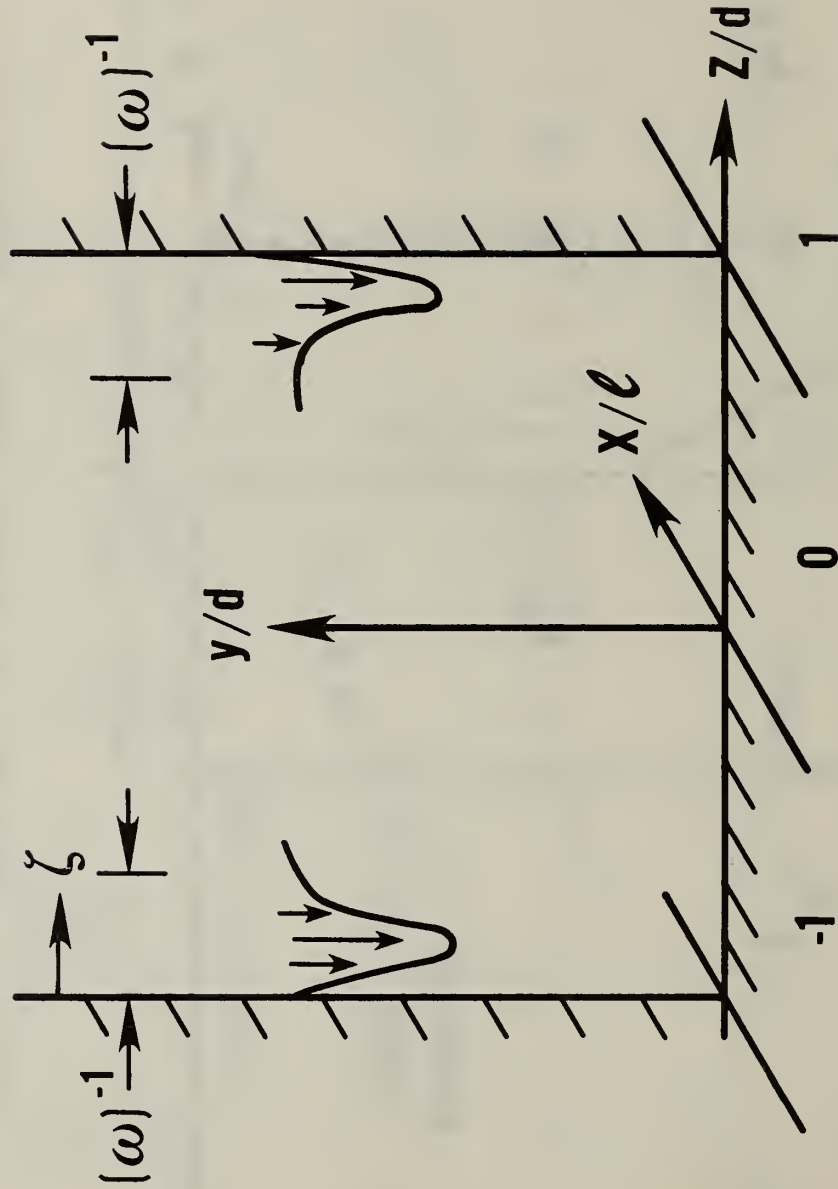
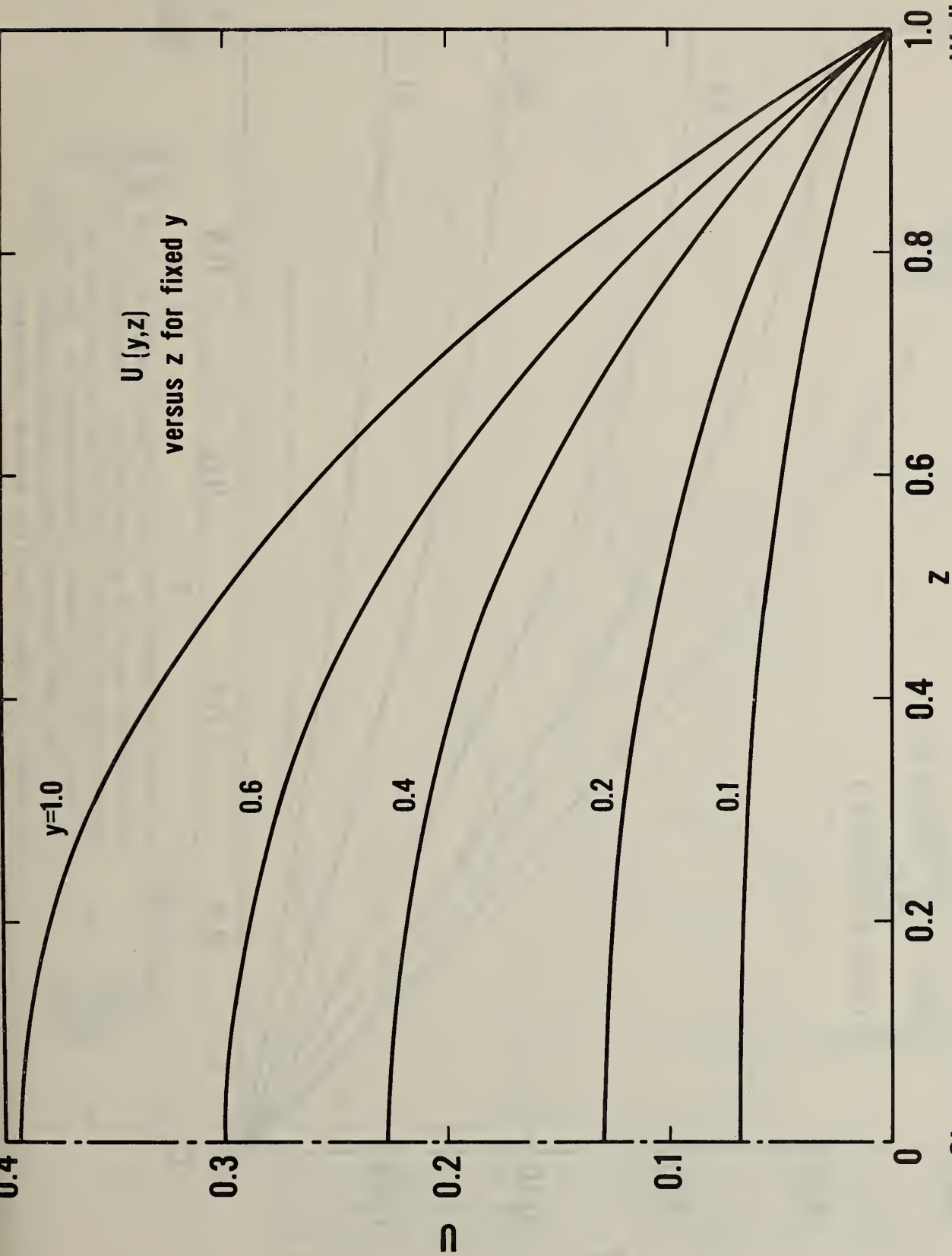


Figure 7. Cross section of the bottom of an intercontainer slot. Velocity distribution of the gas as it approaches the slot bottom is indicated next to each wall



CL Figure 8. Universal velocity profiles for the axial flow in the boundary layer of a slot bottom. The flow is symmetrical about the slot centerline so only one half the slot width is shown. The velocity is zero at the slot bottom and increases toward an asymptotic profile as height,  $y$ , above the bottom increases.

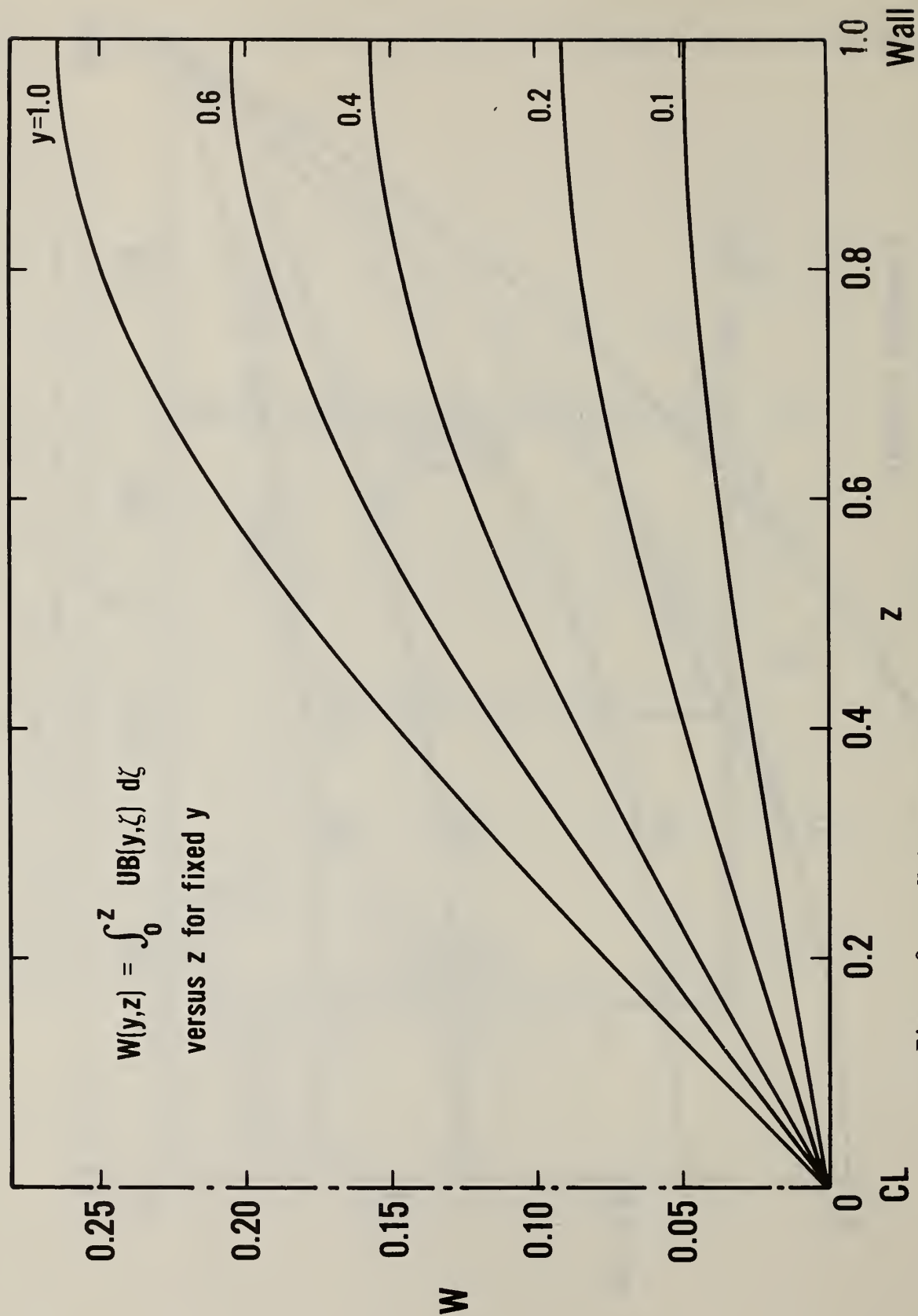


Figure 9. Universal velocity profiles for the transverse flow in the boundary layer of a slot bottom. The flow is antisymmetric about the slot centerline so only one half the slot width is shown. The velocity is zero at the slot bottom and increases toward an asymptotic profile as height,  $y$ , above the slot bottom increases



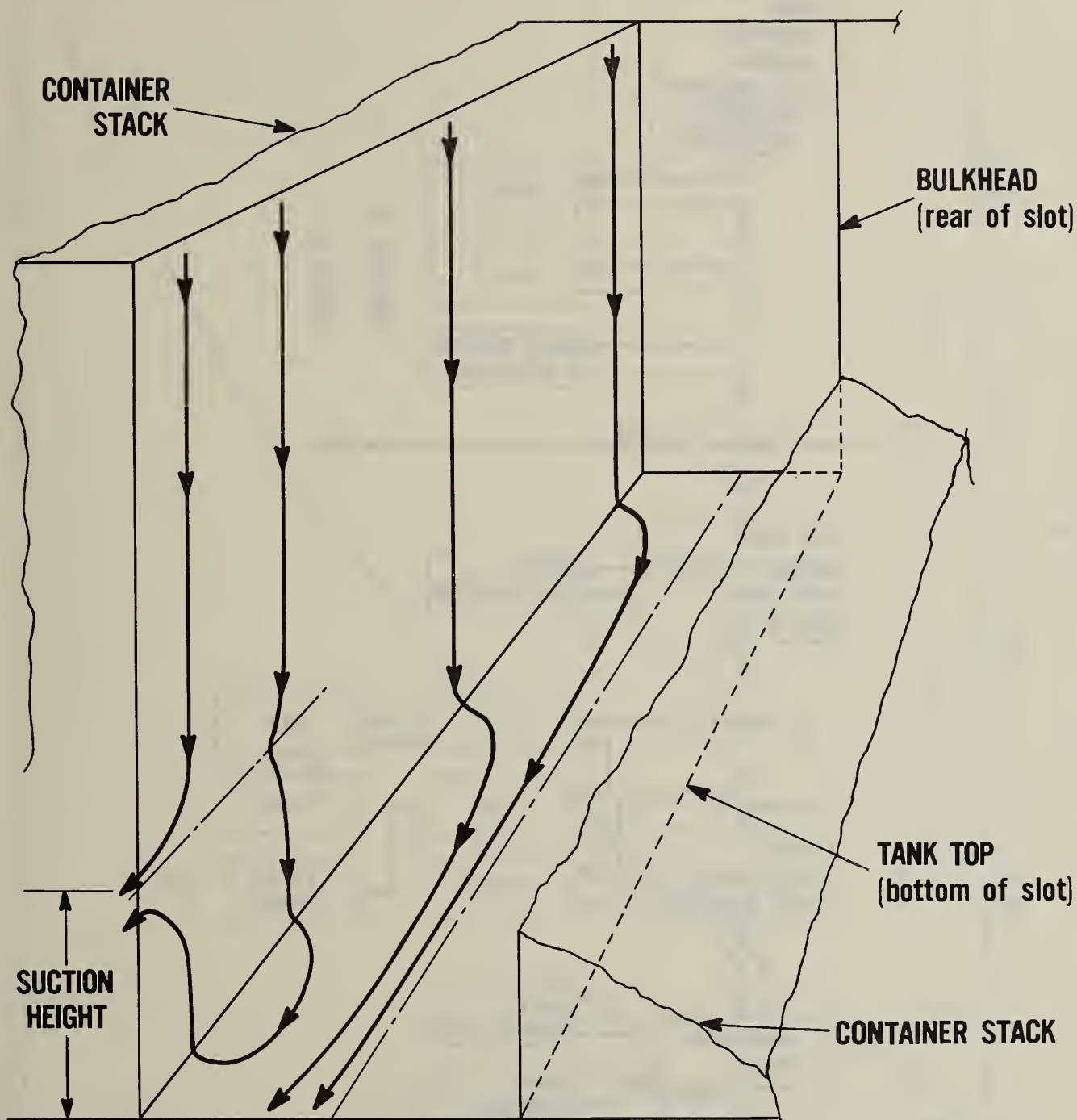


Figure 10. Perspective sketch of an intercontainer slot showing air flow streamlines. The air picks up evaporated spill vapor as it moves in the boundary layer along the bottom of the slot

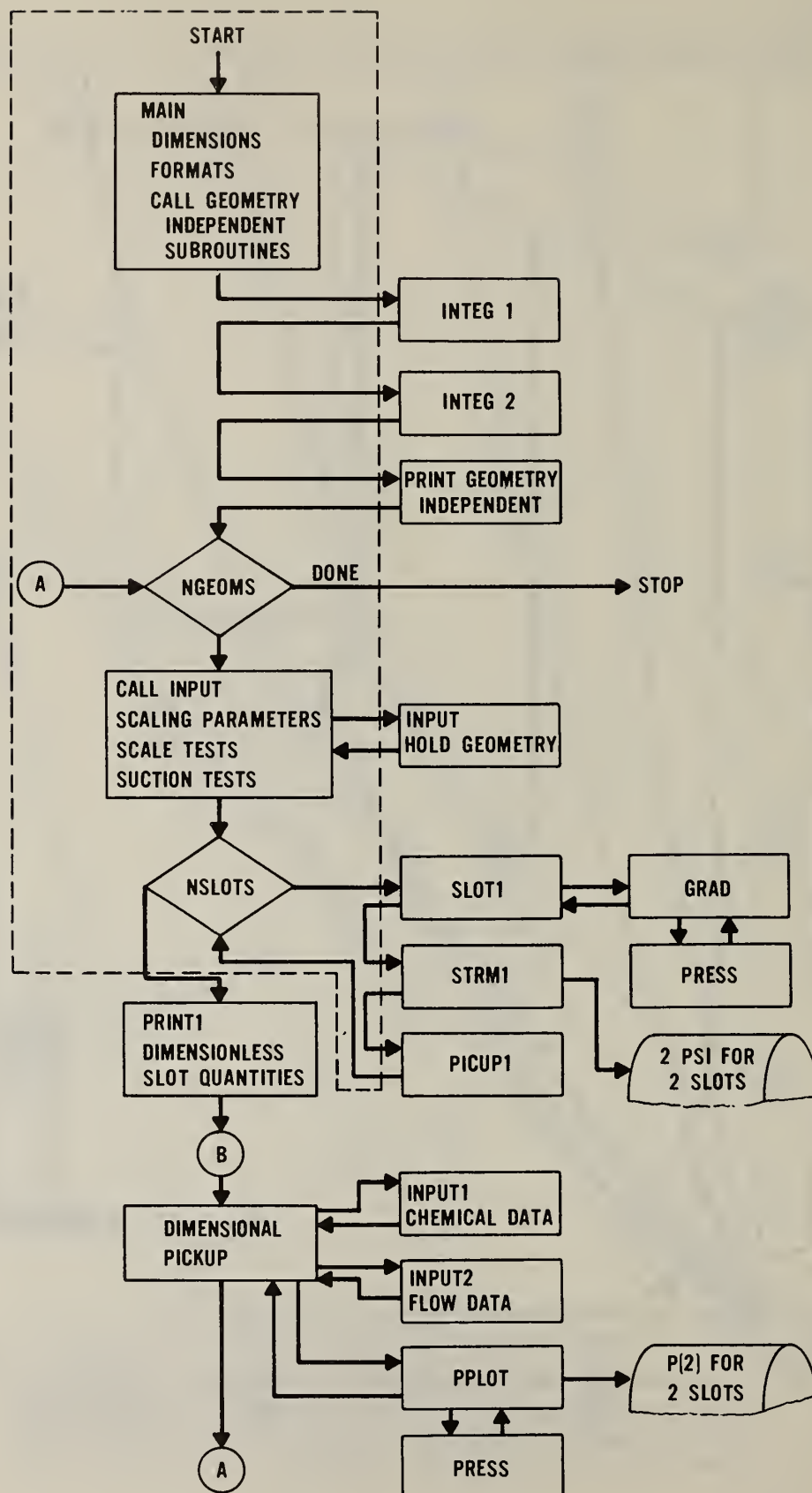


Figure 11. Simplified flow diagram for the computer program

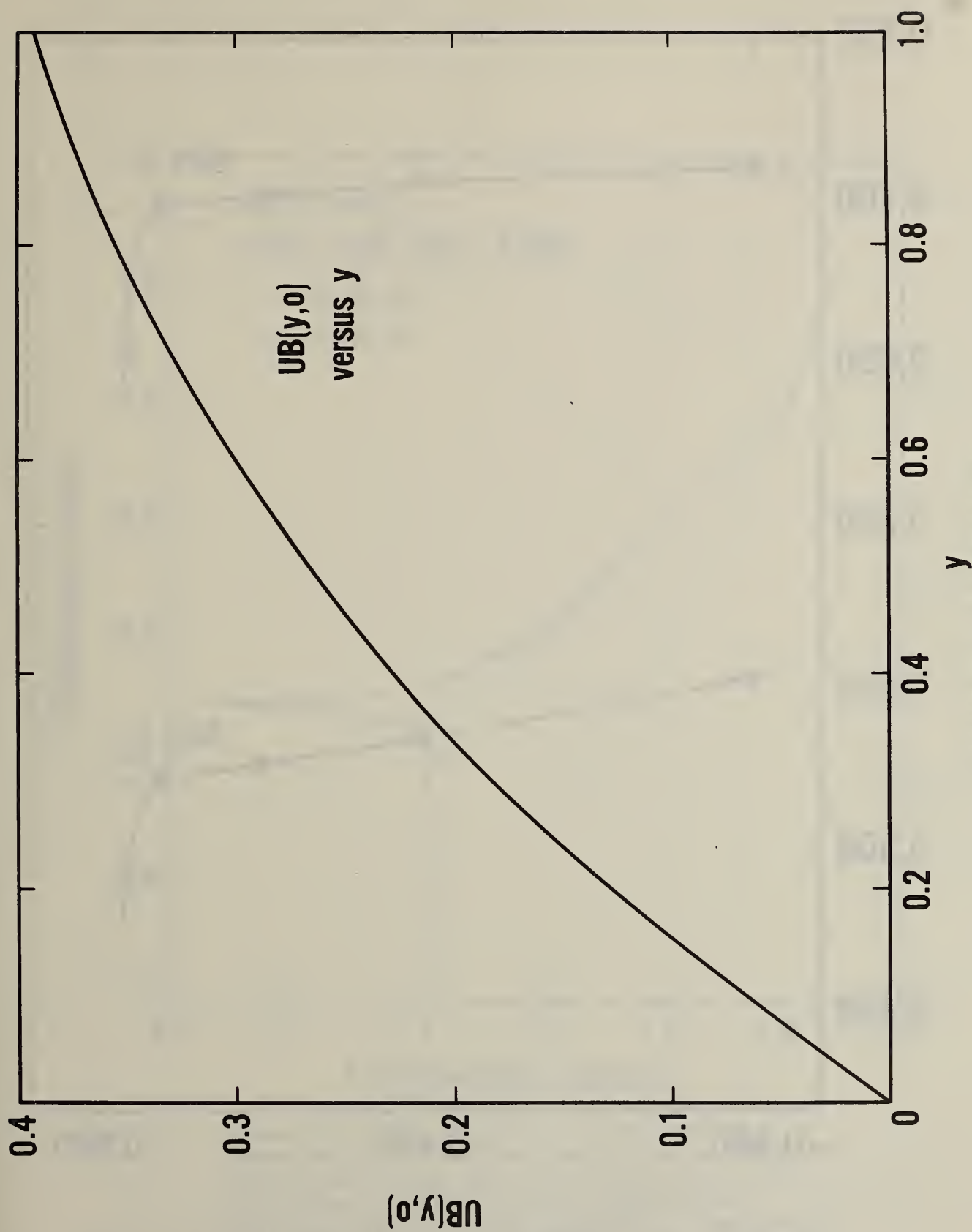


Figure 12. Universal slot bottom axial velocity plotted versus height for a fixed transverse location (centerline)

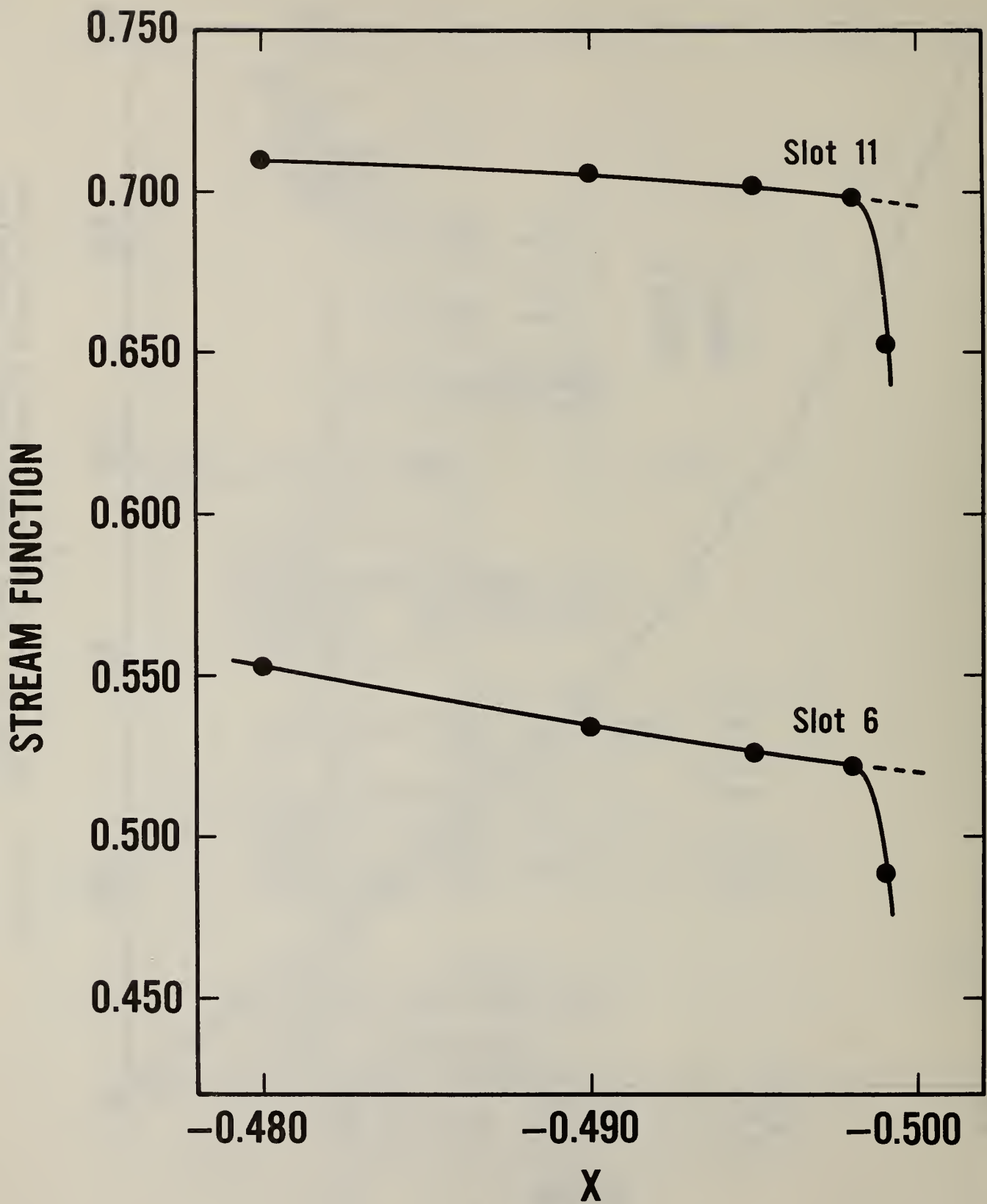


Figure 13. Slot bottom stream function near the intersection of the slot with the hold end void as a function of distance from the intersection (at  $x = -1/2$ )

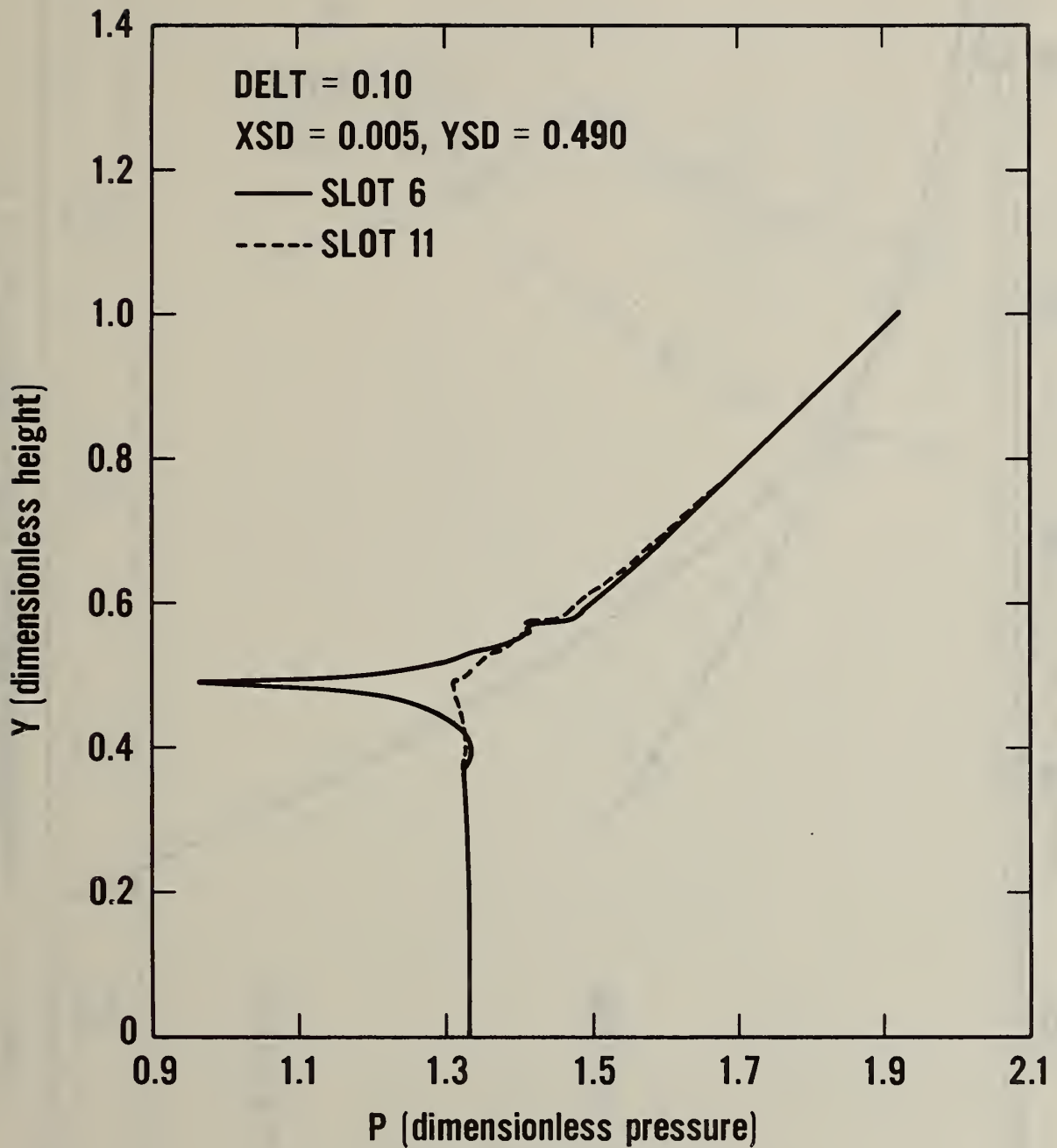


Figure 14. Dimensionless slot pressure as a function of dimensionless height above the slot bottom for two slots: solid line, slot nearest the suction and dotted line, slot furthest from the suction. Pressures calculated single precision. Compare with figure 20-a which is the same case calculated in double-precision



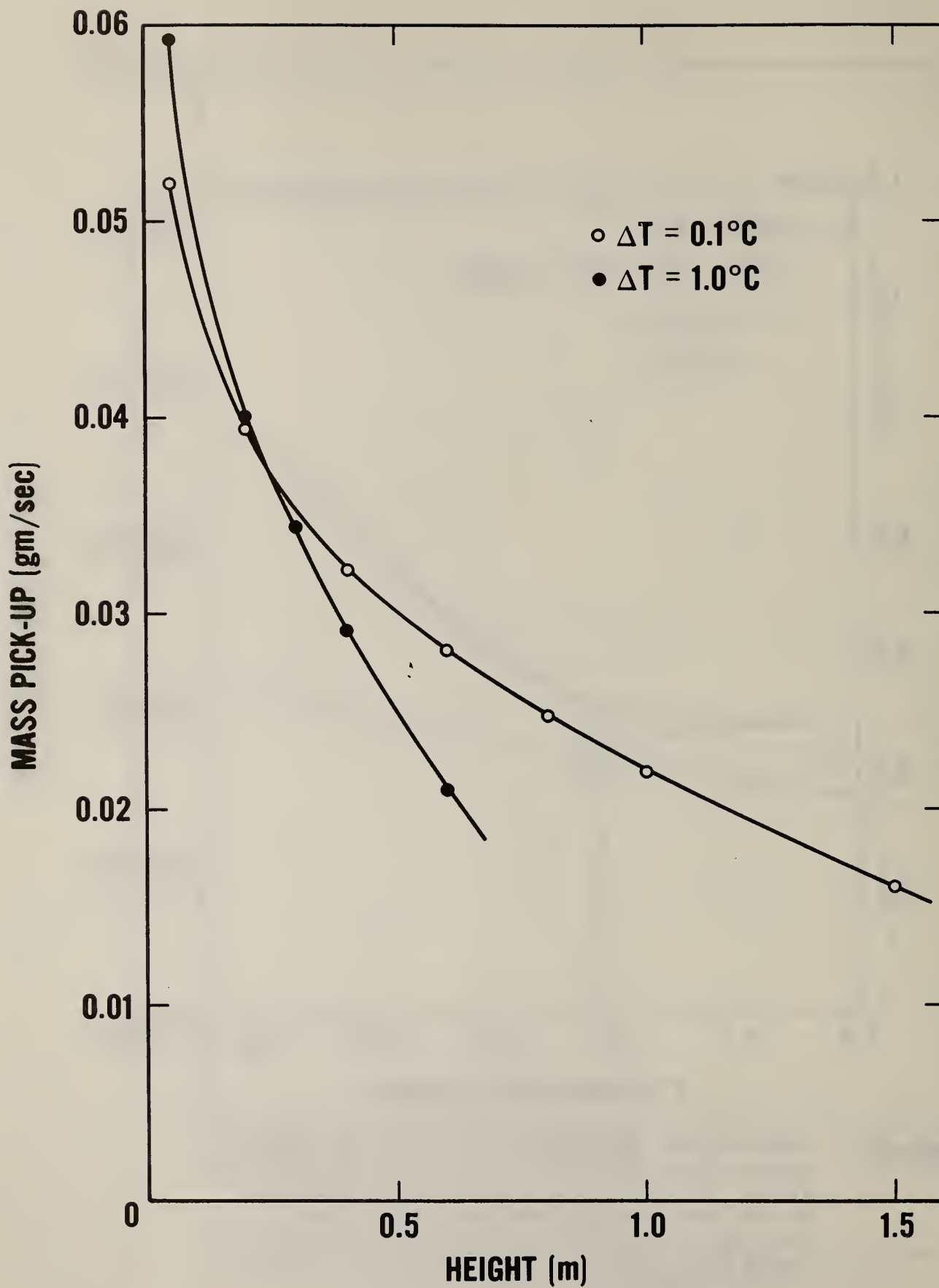


Figure 15. Computed mass pick-up by evaporation and removal by forced ventilation as a function of suction height above the slot bottom for two different amounts of stable stratification

# DIMENSIONLESS MASS PICK-UP

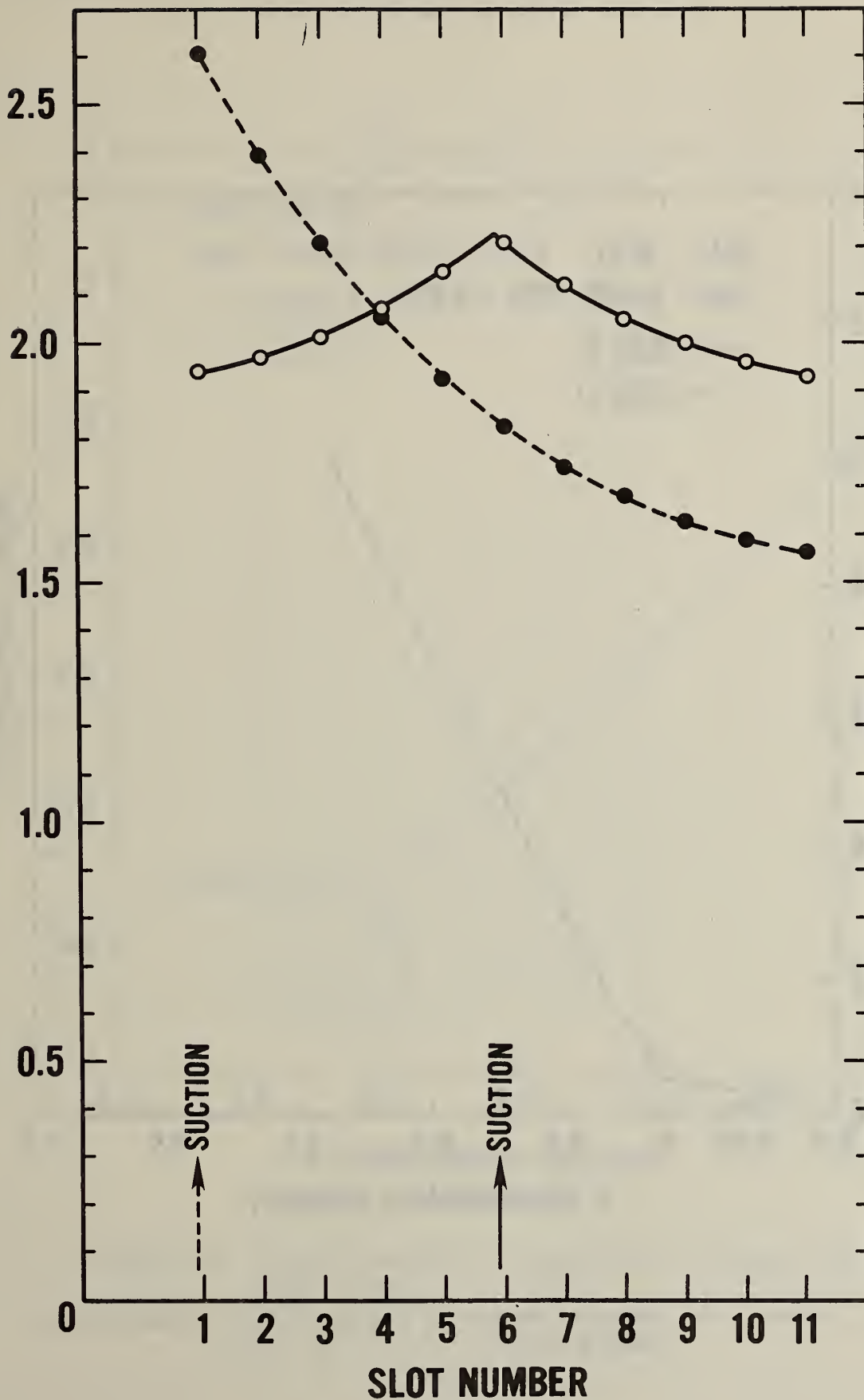


Figure 16. Dimensionless mass pick-up as a function of slot number for a hold containing 11 slots (10 stacks of containlers) for two forced ventilation suction locations: solid line, suction on hold centerline; dotted line, suction at the out-board corner of the hold

Figure 17. Dimensionless pressure as a function of dimensionless height (double precision calculation) stable stratification  $0.1^{\circ}\text{C}$  over height of hold

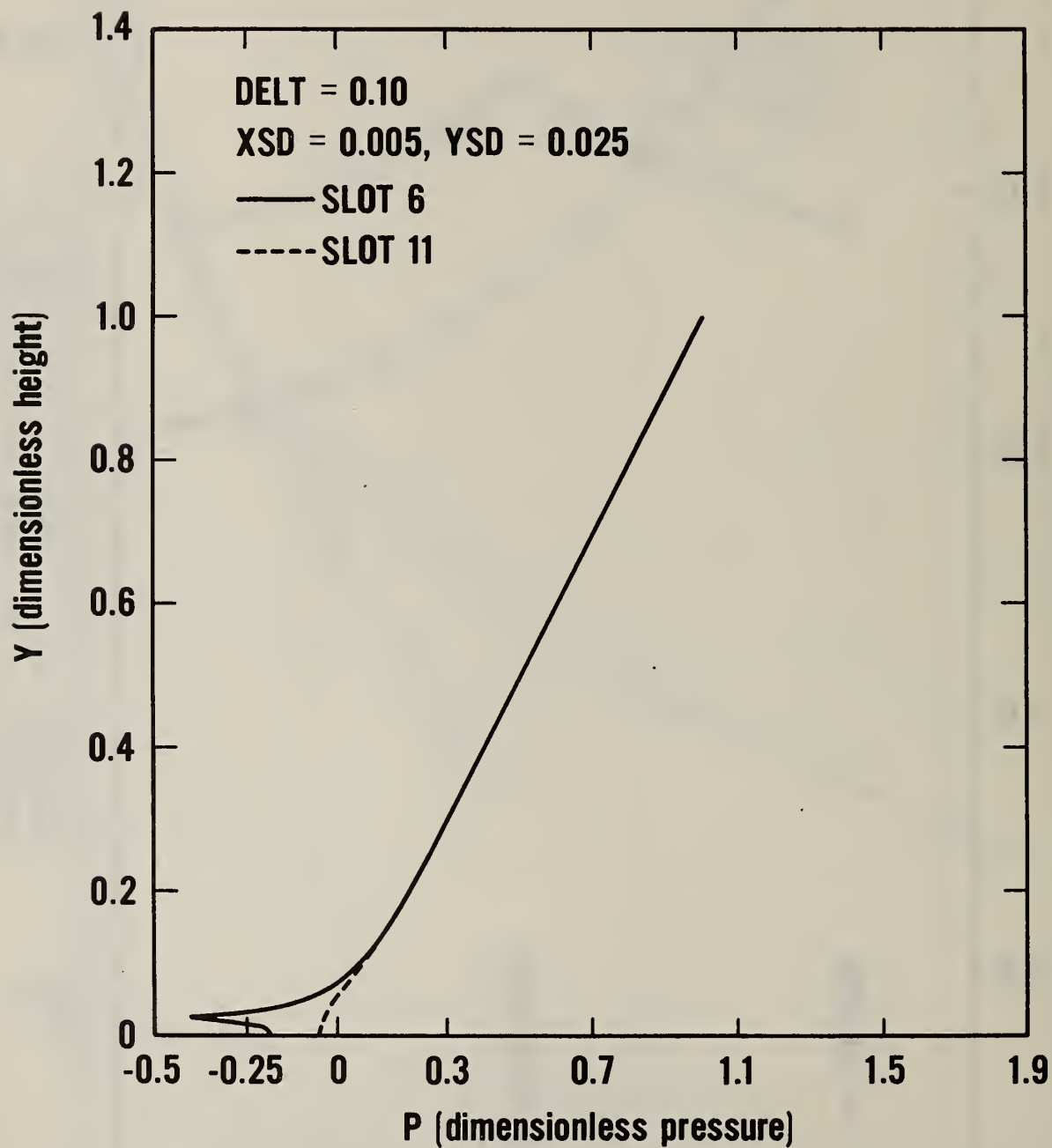


Figure 17a. Physical height of suction 0.05 m, dimensionless height 0.025

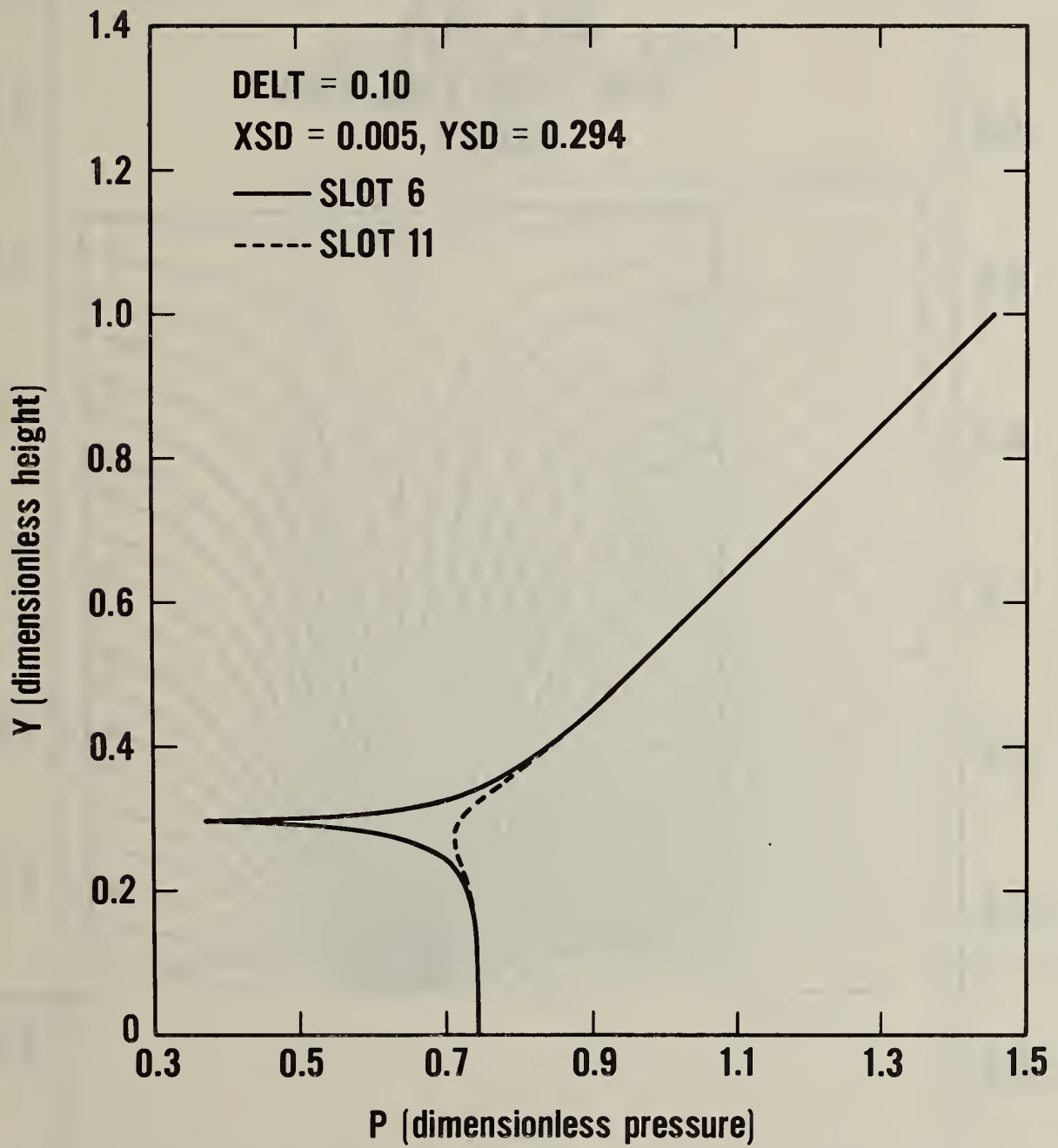


Figure 17b. Physical height of suction 0.60 m, dimensionless height 0.294

Figure 18. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 17a

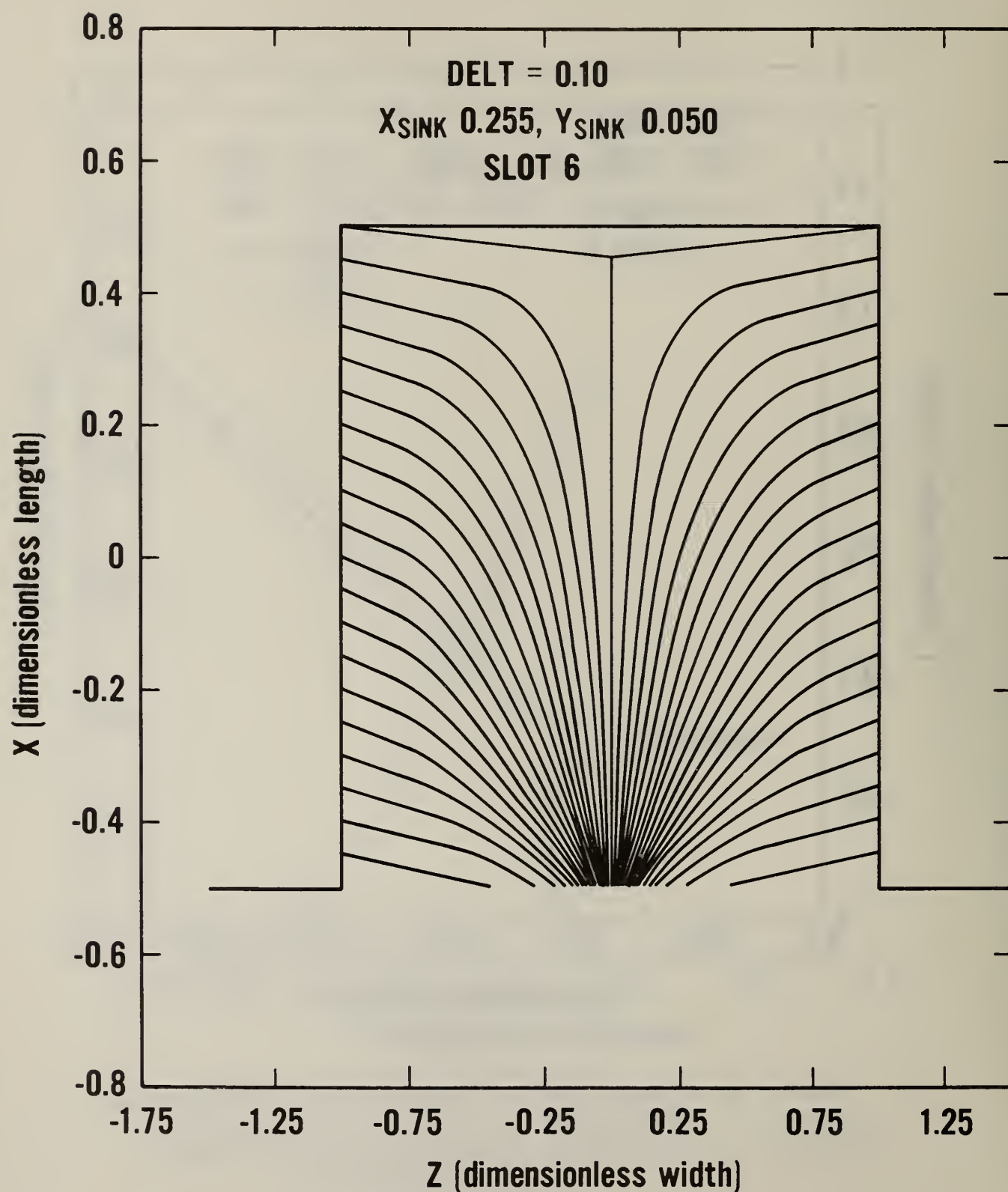


Figure 18a. Streamlines for slot at center (nearest suction)



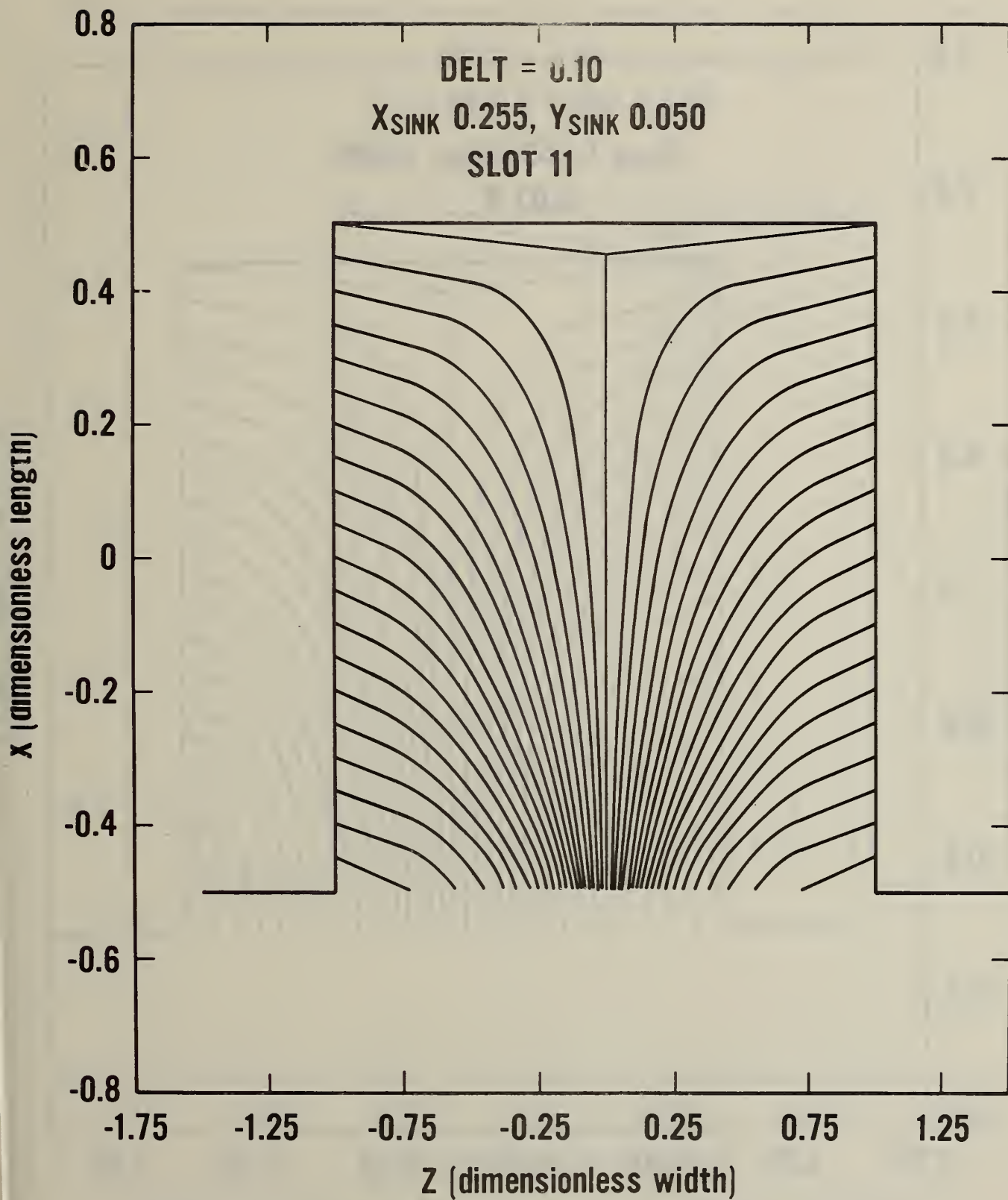


Figure 18b. Streamlines for slot at hold side (furthest from suction)

Figure 19. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 17b

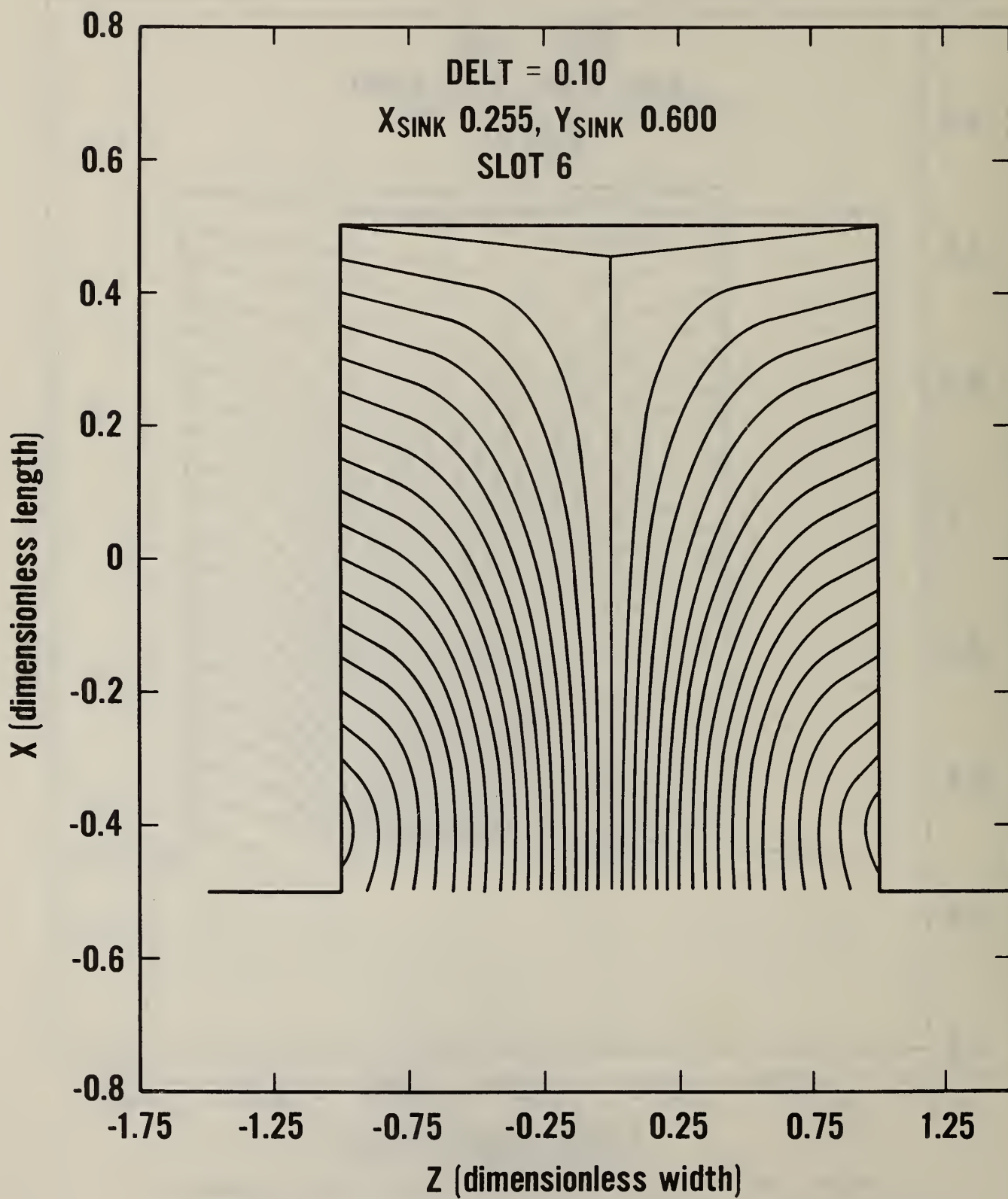


Figure 19a. Streamlines for slot at centerline (nearest suction)

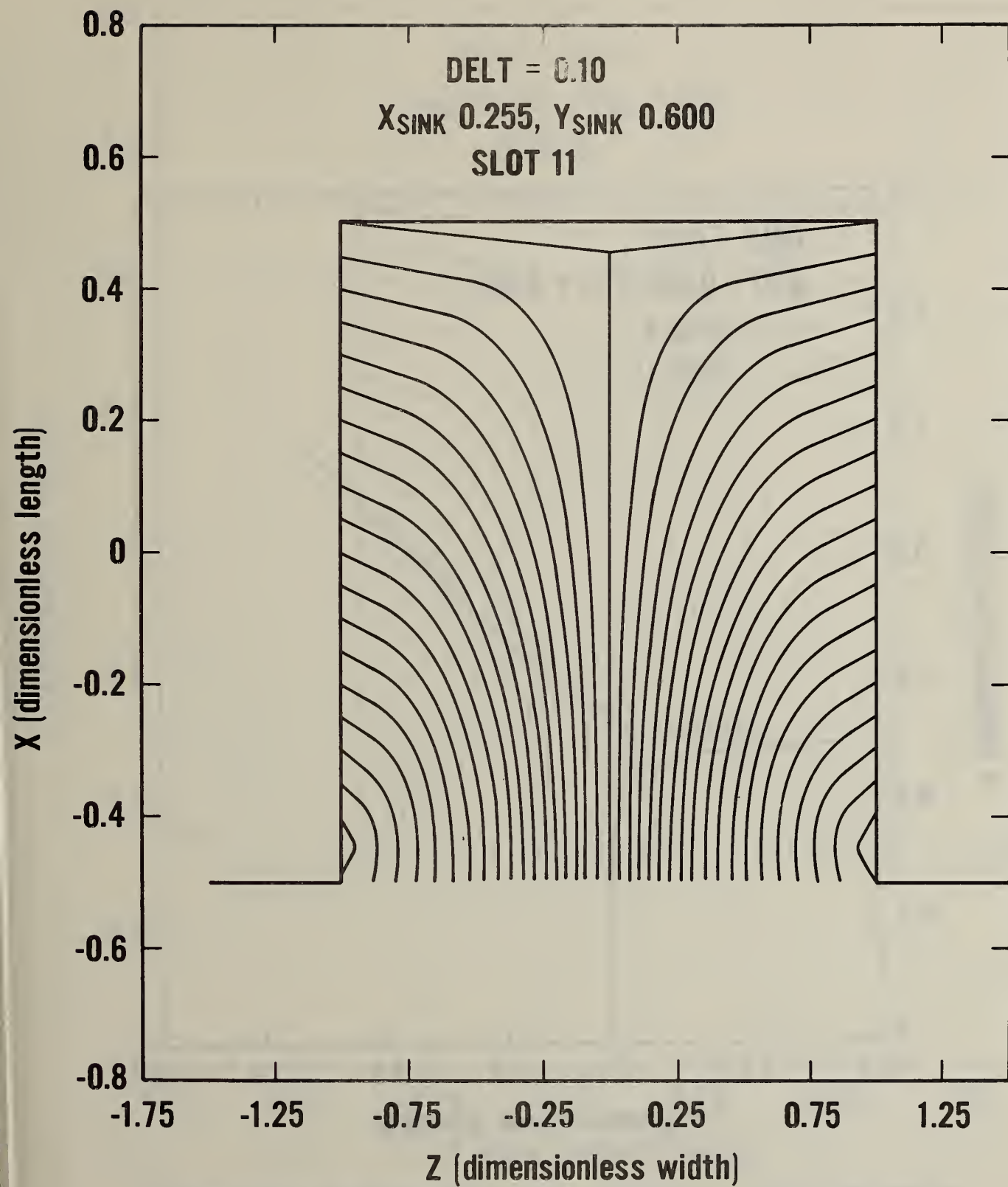


Figure 19b. Streamlines for slot at hold side (furthest from suction)

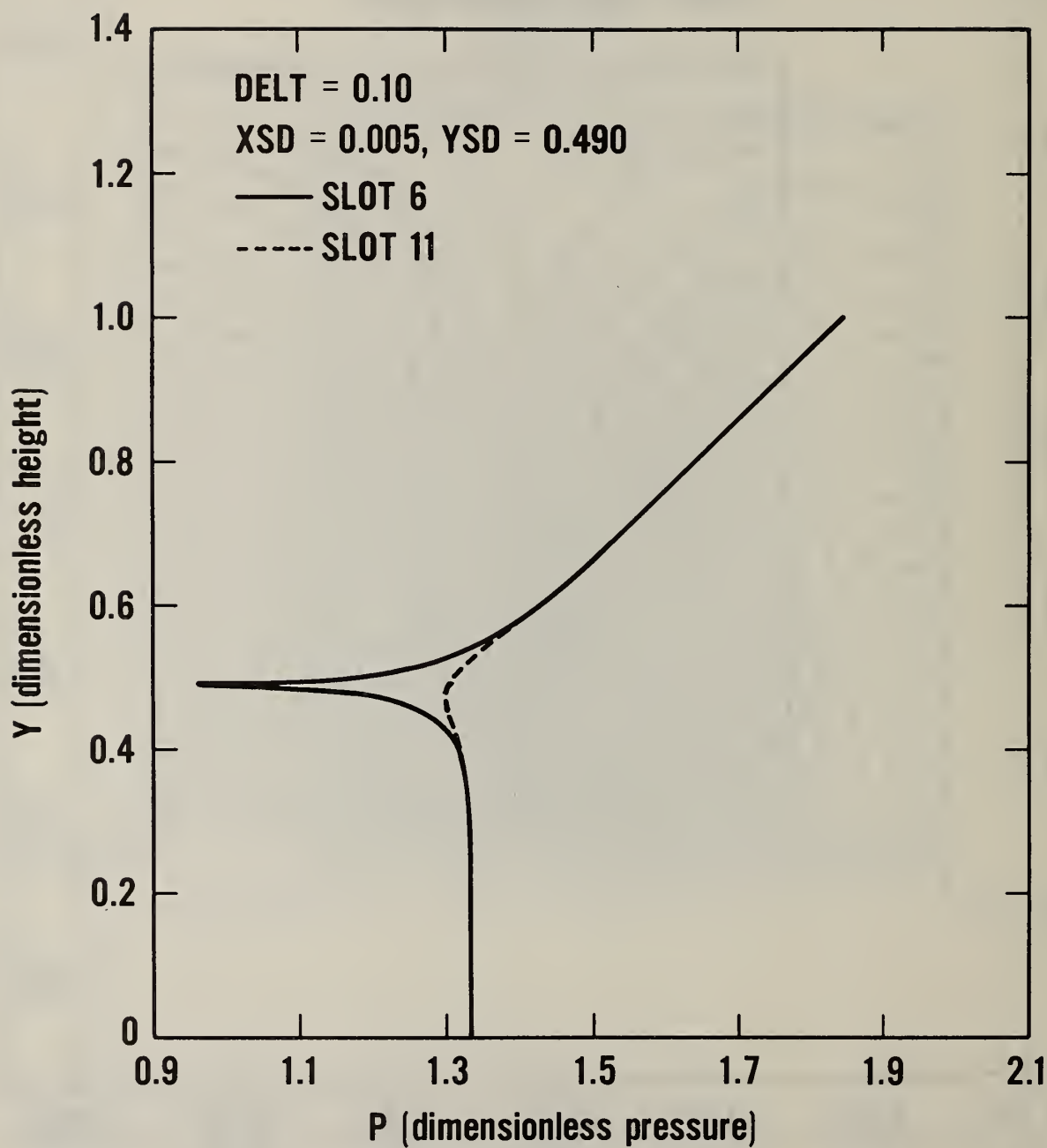


Figure 20a. Dimensionless pressure as a function of dimensionless height (double precision calculation, compare with figure 14). Suction 1 m above hold bottom



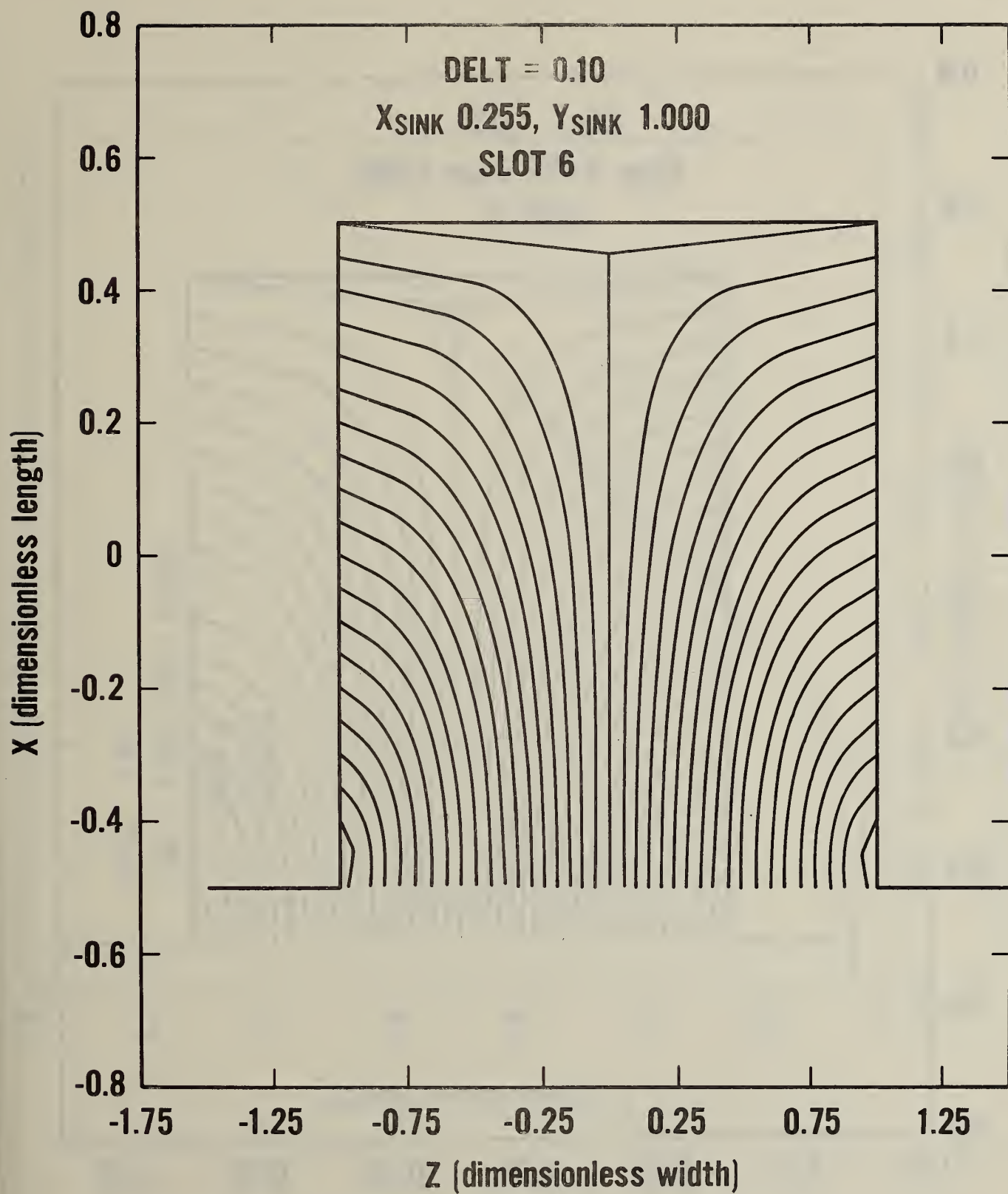


Figure 20b. Slot bottom boundary layer streamlines corresponding to the pressure shown in figure 20a. Centerline slot (nearest suction)



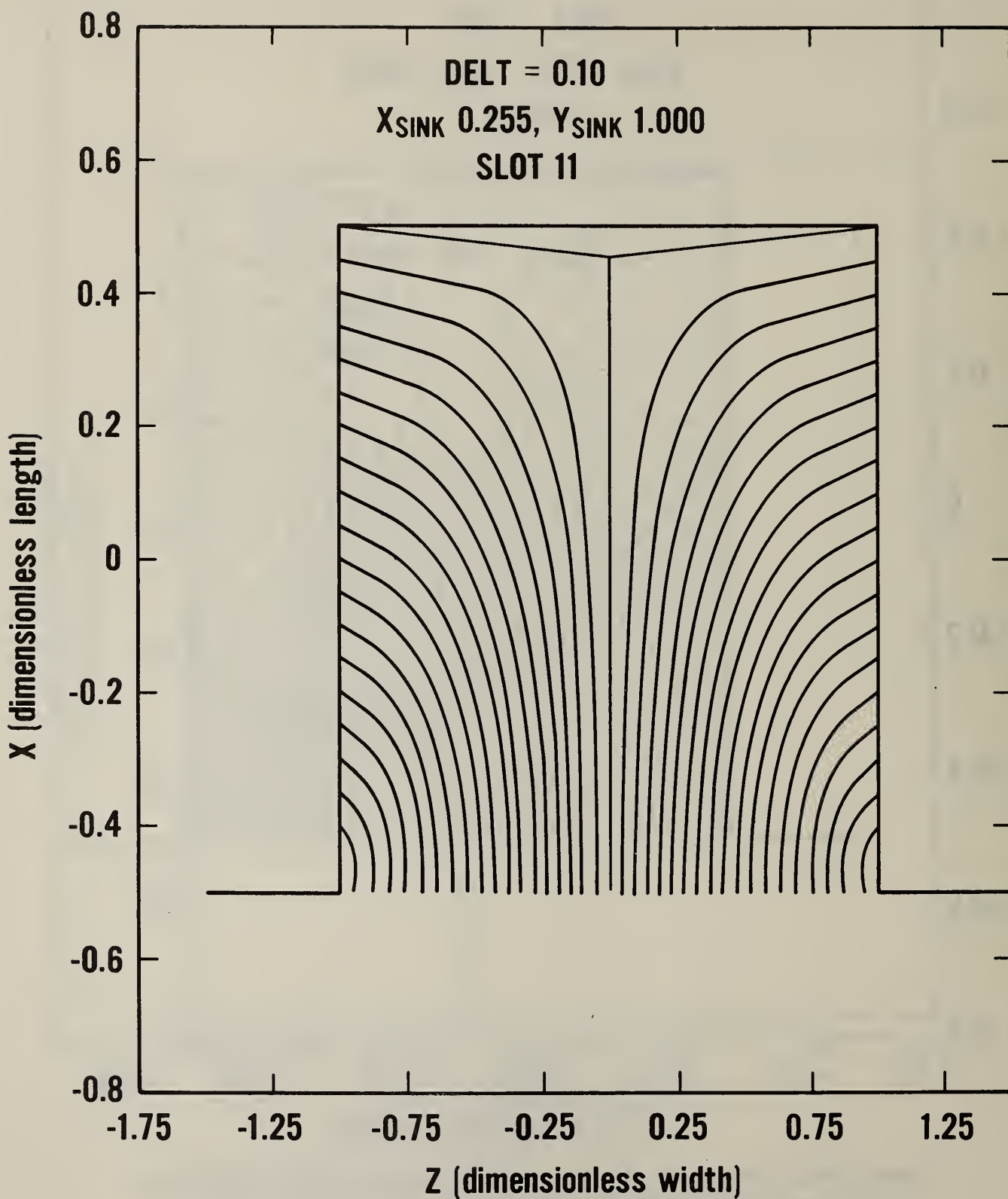


Figure 20c. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 20a. Side slot (furthest from suction)

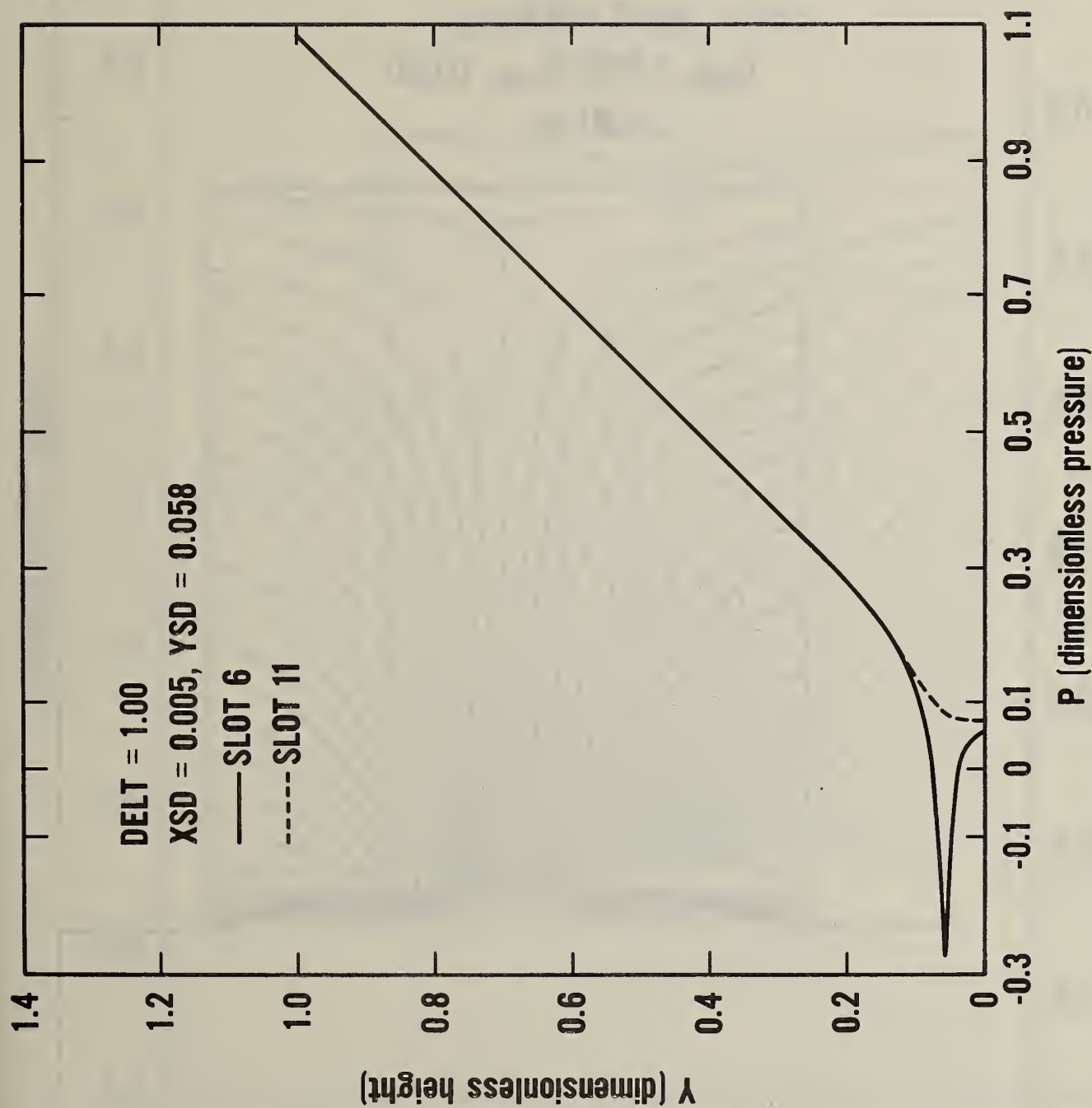


Figure 21a. Dimensionless slot pressure as a function of dimensionless height (double precision-calculation) stable stratification  $1^{\circ}\text{C}$  over height of hold (compare with figure 17)

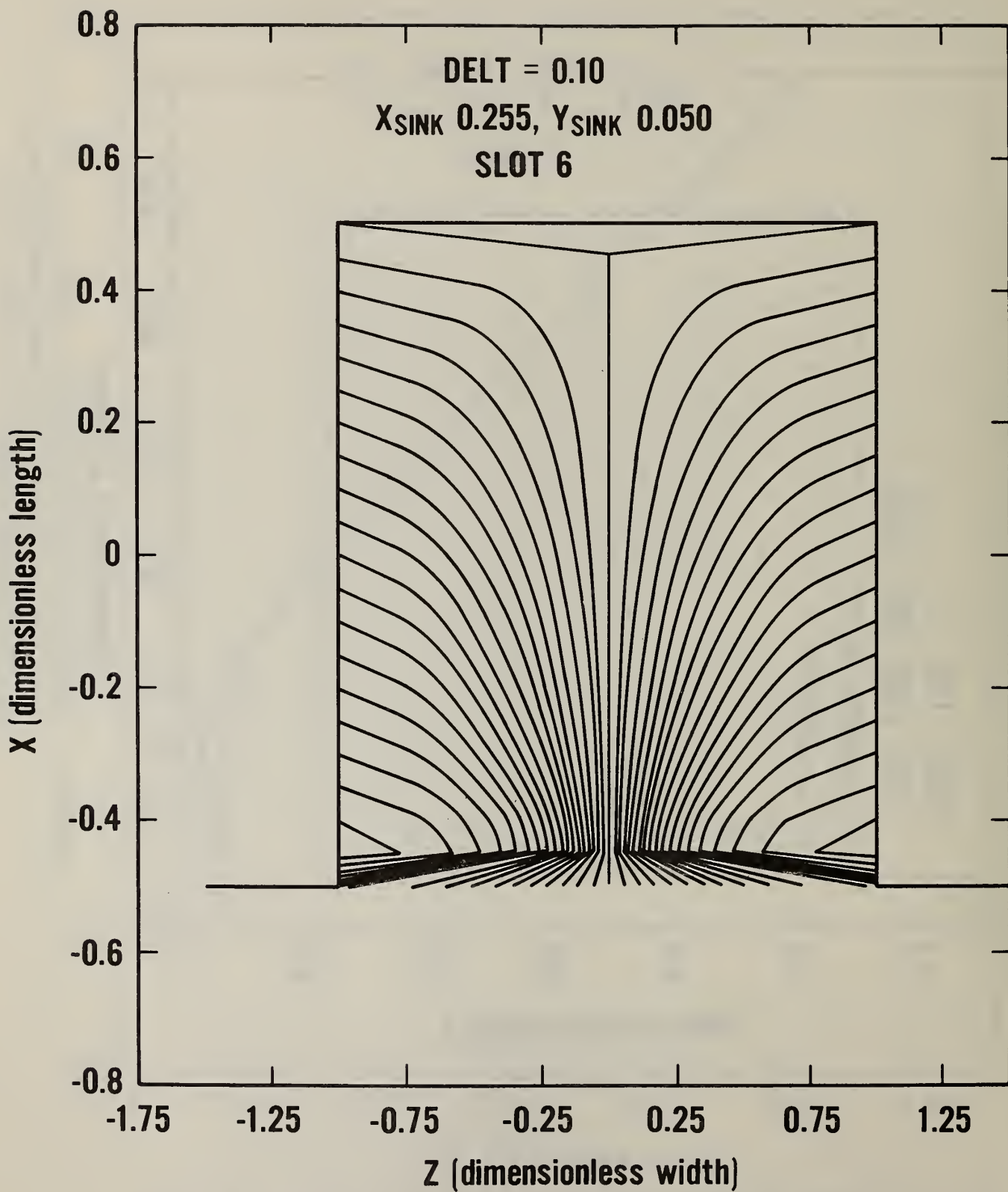


Figure 21b. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 21a. Centerline slot (nearest suction)

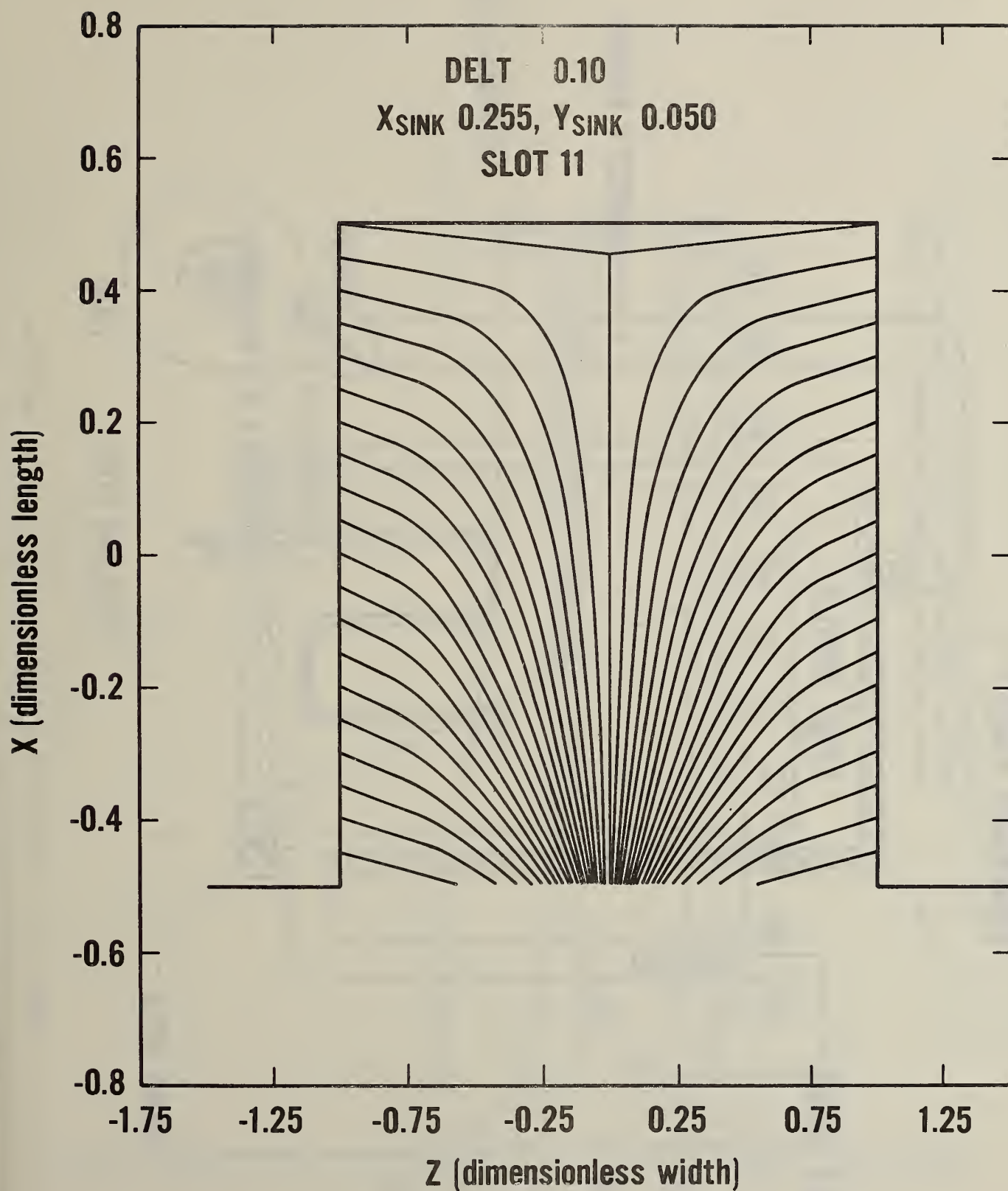


Figure 21c. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 21a. Side slot (furthest from suction)







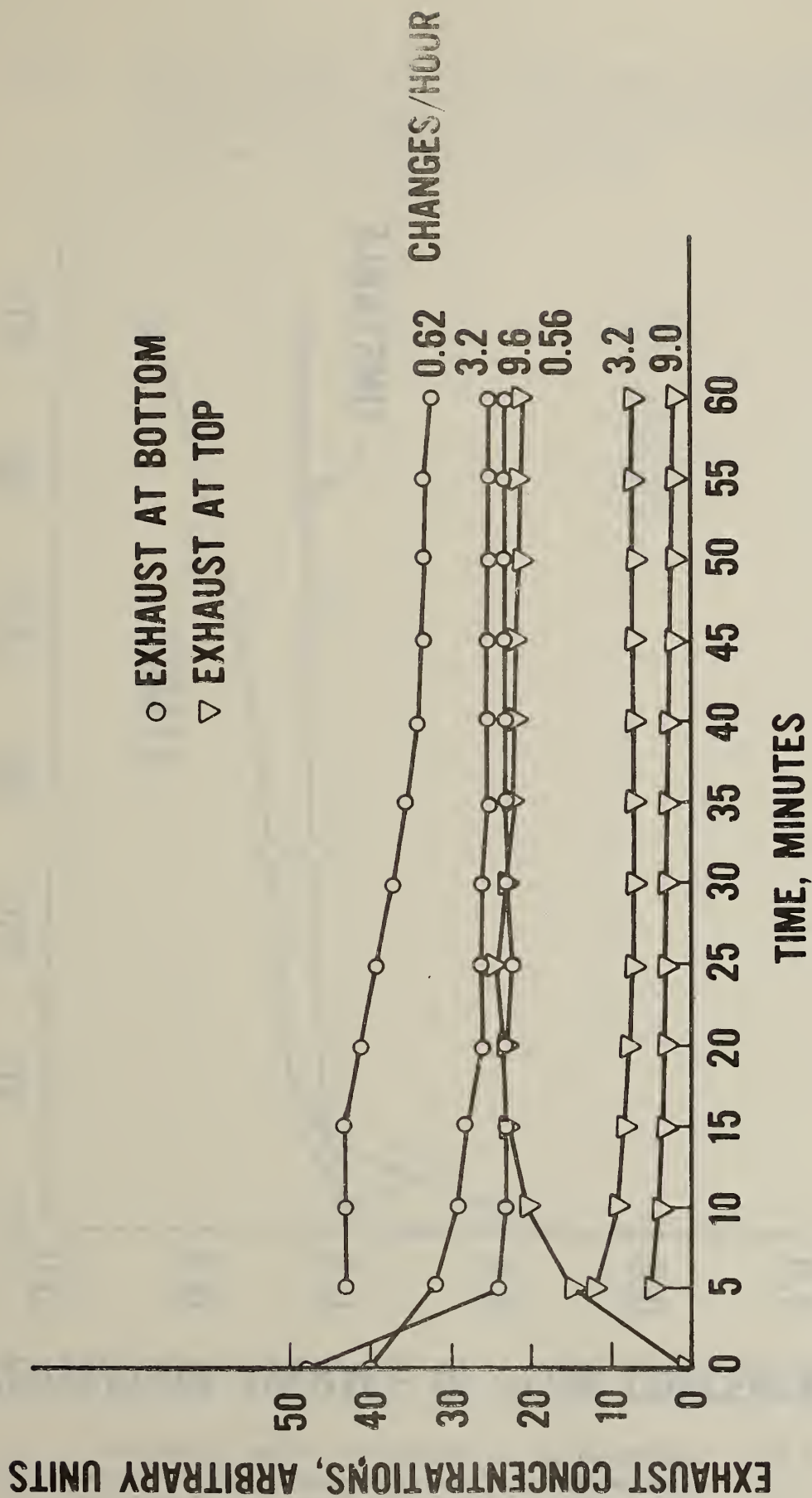


Figure 23. Concentration of combustible vapor in the exhaust duct for several ventilation rates and two suction locations

# CONCENTRATION VERSUS HEIGHT AT 1 AIR CHANGE/HR NORMALIZED BY SATURATED VAPOR CONCENTRATION

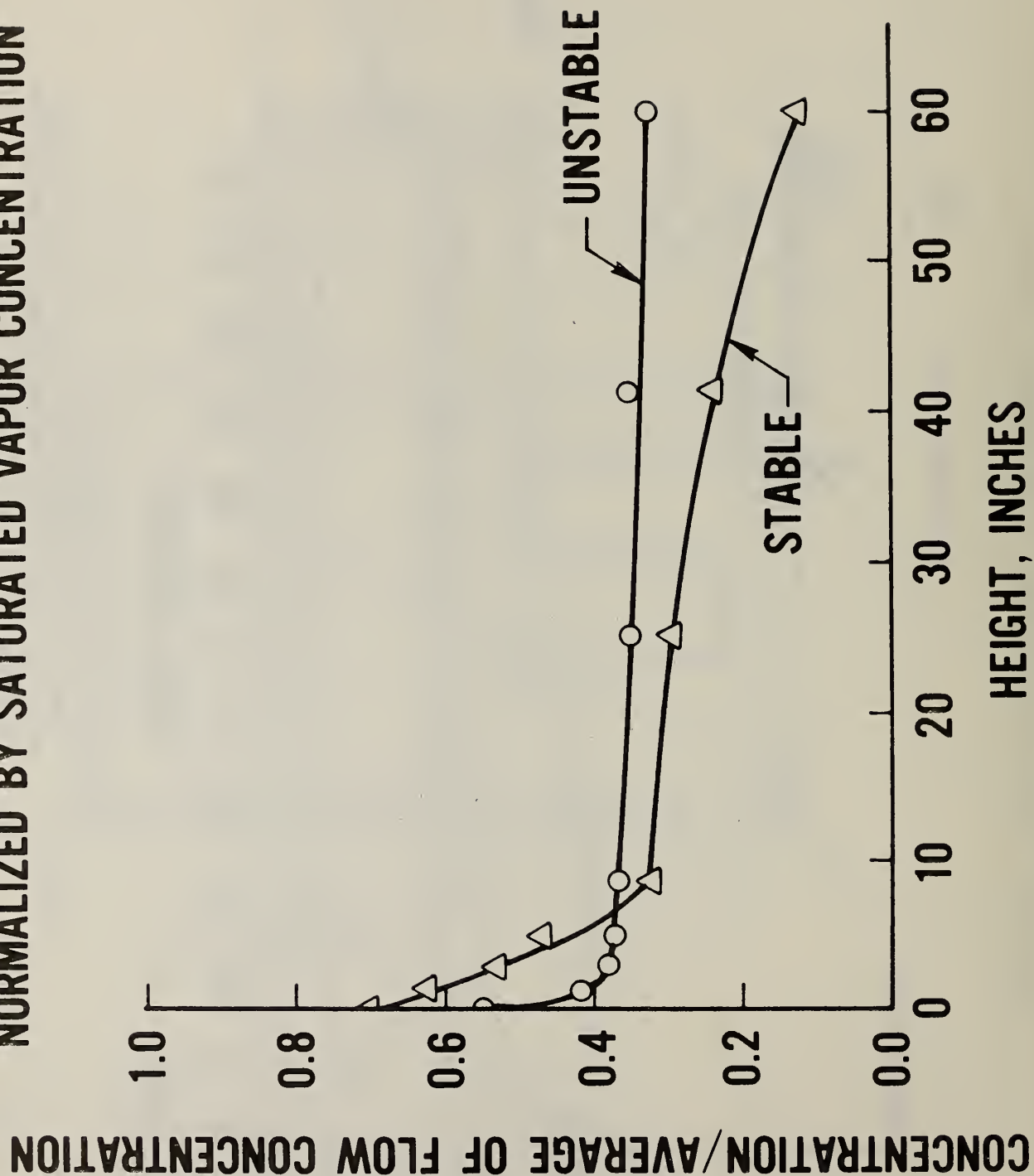


Figure 24. Concentration to combustible vapor inside the experimental enclosures versus height of the sampling point. One air change per hour forced ventilation flow, low suction

Table 1. Vertical pressure gradient effectiveness  $f(\omega)$  dependence upon stratification parameter  $\omega$  defined in Eq. (10) of text.  $f(\omega)$  is the ratio of vertical to horizontal flow capable of being produced by a given pressure gradient.

<u><math>\omega</math></u>	<u><math>f(\omega)</math></u>
0	1
1	.3299
2	.0878
3	.0276
4	.0117
5	.0060

Table 2. Dimensionless Mass Pick-Up  
Suction Height 5 cm Mass Pick-Up

<u>Slot #</u>	<u>Centerline Suction</u>	<u>Side Suction</u>
1	2.01	2.72
2	2.05	2.49
3	2.12	2.29
4	2.25	2.16
5	2.37	2.00
6	2.51	1.91
7	2.34	1.82
8	2.18	1.74
9	2.12	1.74
10	2.03	1.70
11	1.95	1.66

## APPENDIX 1.

### Example of Input Data



1				
0.10	0.8	20.		
51.	0.1	2.46		
12.	11			
20	0.50			
0.0	1920.			
2407.				
1	1			
TEST CASE 5,	HEPTANE	SPIRILL (C.P.)		
0.1	100.	4497.13	98.15	279.09
1				
1.0				10.0

## APPENDIX 2.

Output for the Input Data of Appendix 1



## FIELD CF UB

Y\Z=	C.0CE+00	1.0CE-C1	2.0CE-01	3.0CE-C1	4.0CE-01	5.00E-01	6.0CE-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.100C	6.87E-02	6.82E-02	6.67E-02	6.41E-02	6.04E-02	5.56E-02	4.93E-02	4.13E-02	3.12E-02	1.81E-02	-1.57E-07
0.200C	1.29E-01	1.28E-C1	1.25E-01	1.20E-01	1.13E-01	1.03E-01	9.10E-02	7.55E-02	5.61E-02	3.16E-02	-1.28E-07
0.300C	1.82E-01	1.80E-01	1.76E-01	1.68E-01	1.58E-01	1.44E-01	1.26E-01	1.04E-01	7.60E-02	4.20E-02	-1.07E-07
0.400C	2.27E-01	2.25E-C1	2.19E-01	2.10E-01	1.96E-01	1.78E-01	1.55E-01	1.27E-01	9.22E-02	5.03E-02	-8.97E-08
0.500C	2.66E-01	2.64E-C1	2.57E-01	2.45E-01	2.29E-01	2.07E-01	1.80E-01	1.46E-01	1.06E-01	5.72E-02	-7.59E-08
0.600C	3.00E-01	2.97E-C1	2.89E-01	2.76E-01	2.57E-01	2.32E-01	2.0CE-01	1.62E-01	1.17E-01	6.29E-02	-6.44E-08
0.700C	3.29E-01	3.26E-01	3.17E-01	3.02E-01	2.80E-01	2.53E-01	2.18E-01	1.76E-01	1.26E-01	6.77E-02	-5.48E-08
0.800C	3.53E-01	3.50E-C1	3.40E-01	3.24E-01	3.01E-01	2.71E-01	2.33E-01	1.88E-01	1.34E-01	7.18E-02	-4.66E-08
0.900C	3.75E-01	3.71E-C1	3.61E-01	3.43E-01	3.18E-01	2.86E-01	2.46E-01	1.98E-01	1.41E-01	7.52E-02	-3.98E-08
1.000C	3.93E-01	3.89E-C1	3.78E-01	3.59E-01	3.33E-01	2.99E-01	2.57E-01	2.06E-01	1.47E-01	7.81E-02	-3.39E-08

## FIELD CF UBC

Y\Z=	0.0CE+00	1.00E-C1	2.0CE-01	3.0CE-01	4.00E-01	5.00E-01	6.0CE-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.0C50C	7.04E-01	6.99E-01	6.84E-01	6.58E-01	6.21E-01	5.72E-01	5.09E-01	4.29E-01	3.27E-01	1.93E-01	-3.86E-06

## FIELD CF W = INDEFINATE Z INTEGRAL CF UB

Y\Z=	C.0CE+00	1.0CE-01	2.0CE-01	3.0CE-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.100C	C.0CE+00	6.84E-C3	1.36E-02	2.01E-02	2.64E-02	3.21E-02	3.74E-02	4.19E-02	4.55E-02	4.80E-02	4.89E-02
0.200C	C.0CE+00	1.29E-02	2.55E-02	3.78E-02	4.95E-02	6.03E-02	7.00E-02	7.83E-02	8.49E-02	8.93E-02	9.08E-02
0.300C	C.0CE+00	1.81E-C2	3.59E-02	5.31E-02	6.94E-02	8.45E-02	9.80E-02	1.09E-01	1.18E-01	1.24E-01	1.26E-01
0.400C	0.0CE+00	2.26E-02	4.48E-02	6.63E-02	8.66E-02	1.05E-01	1.22E-01	1.36E-01	1.47E-01	1.54E-01	1.57E-01
0.500C	C.0CE+00	2.65E-C2	5.25E-02	7.76E-02	1.01E-01	1.23E-01	1.42E-01	1.59E-01	1.71E-01	1.79E-01	1.82E-01
0.600C	C.0CE+00	2.98E-C2	5.91E-02	8.74E-02	1.14E-01	1.38E-01	1.60E-01	1.78E-01	1.92E-01	2.01E-01	2.04E-01
0.700C	C.0CE+00	3.27E-C2	6.48E-02	9.57E-02	1.25E-01	1.51E-01	1.75E-01	1.95E-01	2.10E-01	2.20E-01	2.23E-01
0.800C	C.0CE+00	3.52E-02	6.97E-02	1.03E-01	1.34E-01	1.63E-01	1.88E-01	2.09E-01	2.25E-01	2.35E-01	2.39E-01
0.900C	C.0CE+00	3.73E-C2	7.39E-02	1.09E-01	1.42E-01	1.72E-01	1.99E-01	2.21E-01	2.38E-01	2.49E-01	2.53E-01
1.000C	C.0CE+00	3.91E-C2	7.74E-02	1.14E-01	1.49E-01	1.80E-01	2.08E-01	2.31E-01	2.49E-01	2.60E-01	2.64E-01

## FIELD CF W0 = INDEFINATE Z INTEGRAL OF UB0

Y\Z=	C.0CE+00	1.0CE-01	2.0CE-01	3.0CE-01	4.00E-01	5.00E-01	6.0CE-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.0C50C	C.0CE+00	7.01E-C2	1.39E-01	2.06E-01	2.70E-01	3.30E-01	3.84E-01	4.31E-01	4.69E-01	4.95E-01	5.04E-01

INPUT PARAMETERS: DELT = 0.100000 DEG C.  
 TC = 10.00 XL = 51.00 YE = 0.80 ZF = 20.00 M  
 XSLCT = 12.00 YSLCT = 0.10

11 INTERCONTAINER SLOTS SPACED = 2.46 M

NUMBER OF PCINTS TABULATED:  
 AXSLCT = 20

SCALING PARAMETERS  
 GRASH = 9.8459E+03 OMEGA = 7.7690E+00  
 SCRT(F) = 3.9993E-02  
 GRSLCT = 1.9230E+03 CMSLCT = 9.7112E-01  
 SCRT(FS) = 7.9776E-01

THE MODEL ASSUMES THE SLOTS ARE WICELY SPACED  
 COMPARED TO THE VOID WIDTH (AFTER SCALING).  
 INTERCONTAINER SLOT SPACING = 2.46 M

MAIN VOID WIDTH = 0.80 M

SCALED SPACING/VOID WIDTH = 1.22979E-01

SUCTION MOVED TO AVCIC SLOT-VOIC INTERSECTION  
 XSINK = 0.00E+00 XSINK = 2.55E-01

MAIN SUCTION  
 XSINK = 0.2550 M YSINK = 0.6000 M



## INTERCONTAINER SLOT VELOCITY - U

X\LOC=	1.23E+01	9.84E+00	7.38E+00	4.92E+00	2.46E+00	0.00E+00	-2.46E+00	-4.92E+00	-7.38E+00	-9.84E+00	-1.23E+01
-6.0000	8.614E-01	8.542E-01	8.427E-01	8.271E-01	8.079E-01	7.949E-01	8.132E-01	8.328E-01	8.486E-01	8.602E-01	8.676E-01
-5.4000	8.676E-01	8.597E-01	8.483E-01	8.334E-01	8.153E-01	8.032E-01	8.200E-01	8.382E-01	8.532E-01	8.646E-01	8.724E-01
-4.8000	8.590E-01	8.525E-01	8.434E-01	8.316E-01	8.174E-01	8.079E-01	8.210E-01	8.351E-01	8.468E-01	8.553E-01	8.622E-01
-4.2000	8.334E-01	8.290E-01	8.225E-01	8.151E-01	8.056E-01	7.992E-01	8.079E-01	8.173E-01	8.250E-01	8.309E-01	8.352E-01
-3.6000	7.942E-01	7.917E-01	7.882E-01	7.838E-01	7.784E-01	7.748E-01	7.796E-01	7.849E-01	7.892E-01	7.926E-01	7.950E-01
-3.0000	7.490E-01	7.448E-01	7.433E-01	7.413E-01	7.389E-01	7.373E-01	7.394E-01	7.418E-01	7.436E-01	7.451E-01	7.462E-01
-2.4000	6.928E-01	6.926E-01	6.923E-01	6.919E-01	6.913E-01	6.911E-01	6.914E-01	6.919E-01	6.922E-01	6.925E-01	6.927E-01
-1.8000	6.376E-01	6.373E-01	6.383E-01	6.383E-01	6.394E-01	6.399E-01	6.392E-01	6.385E-01	6.380E-01	6.375E-01	6.373E-01
-1.2000	5.821E-01	5.826E-01	5.834E-01	5.844E-01	5.856E-01	5.866E-01	5.852E-01	5.840E-01	5.830E-01	5.822E-01	5.816E-01
-0.6000	5.273E-01	5.279E-01	5.289E-01	5.301E-01	5.316E-01	5.327E-01	5.312E-01	5.297E-01	5.284E-01	5.274E-01	5.268E-01
0.0000	4.737E-01	4.744E-01	4.754E-01	4.767E-01	4.782E-01	4.794E-01	4.779E-01	4.763E-01	4.750E-01	4.740E-01	4.733E-01
0.6000	4.217E-01	4.224E-01	4.233E-01	4.246E-01	4.261E-01	4.272E-01	4.256E-01	4.241E-01	4.229E-01	4.219E-01	4.213E-01
1.2000	3.712E-01	3.718E-01	3.727E-01	3.738E-01	3.752E-01	3.763E-01	3.748E-01	3.735E-01	3.723E-01	3.714E-01	3.708E-01
1.8000	3.222E-01	3.227E-01	3.235E-01	3.245E-01	3.257E-01	3.267E-01	3.254E-01	3.242E-01	3.232E-01	3.224E-01	3.218E-01
2.4000	2.744E-01	2.749E-01	2.756E-01	2.765E-01	2.775E-01	2.783E-01	2.772E-01	2.762E-01	2.753E-01	2.746E-01	2.741E-01
3.0000	2.279E-01	2.283E-01	2.288E-01	2.296E-01	2.304E-01	2.311E-01	2.302E-01	2.293E-01	2.286E-01	2.280E-01	2.276E-01
3.6000	1.823E-01	1.826E-01	1.830E-01	1.836E-01	1.843E-01	1.849E-01	1.841E-01	1.834E-01	1.829E-01	1.824E-01	1.821E-01
4.2000	1.375E-01	1.377E-01	1.380E-01	1.385E-01	1.390E-01	1.394E-01	1.388E-01	1.383E-01	1.379E-01	1.376E-01	1.373E-01
4.8000	9.322E-02	9.338E-02	9.361E-02	9.389E-02	9.423E-02	9.450E-02	9.414E-02	9.390E-02	9.351E-02	9.329E-02	9.313E-02
5.4000	4.937E-02	4.945E-02	4.956E-02	4.971E-02	4.988E-02	5.001E-02	4.983E-02	4.966E-02	4.952E-02	4.940E-02	4.933E-02
6.0000	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03

## INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = 12.30

X\Z=	C.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	C.000E+00	6.041E-02	1.200E-01	1.778E-01	2.329E-01	2.843E-01	3.308E-01	3.712E-01	4.038E-01	4.261E-01	4.345E-01
-5.4000	C.000E+00	6.085E-02	1.208E-01	1.790E-01	2.345E-01	2.863E-01	3.332E-01	3.739E-01	4.067E-01	4.292E-01	4.376E-01
-4.8000	C.000E+00	6.025E-02	1.196E-01	1.773E-01	2.322E-01	2.835E-01	3.299E-01	3.702E-01	4.026E-01	4.250E-01	4.333E-01
-4.2000	C.000E+00	5.845E-02	1.161E-01	1.720E-01	2.253E-01	2.750E-01	3.201E-01	3.592E-01	3.907E-01	4.123E-01	4.204E-01
-3.6000	C.000E+00	5.570E-02	1.106E-01	1.639E-01	2.147E-01	2.621E-01	3.050E-01	3.423E-01	3.723E-01	3.929E-01	4.006E-01
-3.0000	C.000E+00	5.232E-02	1.039E-01	1.539E-01	2.017E-01	2.462E-01	2.865E-01	3.215E-01	3.497E-01	3.691E-01	3.763E-01
-2.4000	C.000E+00	4.859E-02	9.649E-02	1.430E-01	1.873E-01	2.287E-01	2.661E-01	2.986E-01	3.248E-01	3.428E-01	3.495E-01
-1.8000	C.000E+00	4.472E-02	8.880E-02	1.316E-01	1.724E-01	2.104E-01	2.449E-01	2.748E-01	2.989E-01	3.154E-01	3.216E-01
-1.2000	C.000E+00	4.082E-02	8.106E-02	1.201E-01	1.574E-01	1.921E-01	2.236E-01	2.508E-01	2.728E-01	2.880E-01	2.936E-01
-0.6000	C.000E+00	3.698E-02	7.343E-02	1.088E-01	1.425E-01	1.740E-01	2.025E-01	2.272E-01	2.471E-01	2.609E-01	2.659E-01
0.0000	C.000E+00	3.323E-02	6.595E-02	9.776E-02	1.281E-01	1.563E-01	1.819E-01	2.042E-01	2.221E-01	2.344E-01	2.389E-01
0.6000	C.000E+00	2.958E-02	5.873E-02	8.702E-02	1.140E-01	1.392E-01	1.620E-01	1.817E-01	1.977E-01	2.086E-01	2.127E-01
1.2000	C.000E+00	2.604E-02	5.170E-02	7.660E-02	1.004E-01	1.225E-01	1.426E-01	1.600E-01	1.740E-01	1.836E-01	1.872E-01
1.8000	C.000E+00	2.260E-02	4.487E-02	6.648E-02	8.709E-02	1.063E-01	1.237E-01	1.388E-01	1.510E-01	1.594E-01	1.625E-01
2.4000	C.000E+00	1.925E-02	3.822E-02	5.664E-02	7.419E-02	9.057E-02	1.054E-01	1.183E-01	1.286E-01	1.358E-01	1.384E-01
3.0000	C.000E+00	1.593E-02	3.174E-02	4.703E-02	6.160E-02	7.520E-02	8.752E-02	9.821E-02	1.068E-01	1.127E-01	1.149E-01
3.6000	C.000E+00	1.273E-02	2.539E-02	3.762E-02	4.928E-02	6.016E-02	7.001E-02	7.856E-02	8.544E-02	9.013E-02	9.194E-02
4.2000	C.000E+00	9.641E-03	1.914E-02	2.837E-02	3.716E-02	4.536E-02	5.280E-02	5.924E-02	6.443E-02	6.801E-02	6.933E-02

4.800C C.00CE+00 6.533E-C3 1.298E-02 1.524E-C2 2.320E-02 3.077E-02 3.580E-02 4.019E-02 4.370E-02 4.612E-02 4.702E-02  
 5.400C C.00CE+00 3.463E-C3 6.876E-03 1.019E-02 1.335E-02 1.629E-02 1.896E-02 2.128E-02 2.314E-02 2.443E-02 2.490E-02  
 6.000C C.00CE+00 4.011E-C4 7.964E-04 1.180E-C3 1.546E-03 1.687E-03 2.196E-03 2.465E-03 2.681E-03 2.829E-03 2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = 9.84

X\Z= C.00E+00 1.00E-01 2.00E-01 3.00E-01 4.00E-01 5.00E-01 6.00E-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00  
 -6.000C C.00CE+00 5.991E-C2 1.190E-01 1.763E-01 2.309E-01 2.819E-01 3.281E-01 3.681E-01 4.004E-01 4.226E-01 4.308E-01  
 -5.400C C.00CE+00 6.030E-02 1.197E-01 1.774E-01 2.324E-01 2.837E-01 3.302E-01 3.705E-01 4.030E-01 4.253E-01 4.336E-01  
 -4.800C C.00CE+00 5.979E-C2 1.187E-01 1.759E-01 2.305E-01 2.813E-01 3.274E-01 3.674E-01 3.996E-01 4.218E-01 4.300E-01  
 -4.200C C.00CE+00 5.814E-C2 1.155E-01 1.711E-01 2.241E-01 2.736E-01 3.184E-01 3.573E-01 3.865E-01 4.101E-01 4.181E-01  
 -3.600C C.00CE+00 5.552E-C2 1.103E-01 1.634E-01 2.140E-01 2.613E-01 3.041E-01 3.412E-01 3.711E-01 3.917E-01 3.993E-01  
 -3.000C C.00CE+00 5.224E-C2 1.037E-01 1.537E-01 2.014E-01 2.458E-01 2.861E-01 3.210E-01 3.491E-01 3.685E-01 3.757E-01  
 -2.400C C.00CE+00 4.858E-C2 9.645E-02 1.429E-01 1.872E-01 2.286E-01 2.660E-01 2.985E-01 3.246E-01 3.426E-01 3.493E-01  
 -1.800C C.00CE+00 4.474E-C2 8.833E-02 1.316E-01 1.724E-01 2.105E-01 2.450E-01 2.749E-01 2.990E-01 3.156E-01 3.217E-01  
 -1.200C C.00CE+00 4.068E-C2 8.114E-02 1.202E-01 1.575E-01 1.923E-01 2.238E-01 2.511E-01 2.731E-01 2.882E-01 2.938E-01  
 -0.600C C.00CE+00 3.703E-C2 7.352E-02 1.069E-01 1.427E-01 1.742E-01 2.028E-01 2.275E-01 2.475E-01 2.612E-01 2.663E-01  
 0.000C C.00CE+00 3.327E-C2 6.607E-02 9.790E-02 1.283E-01 1.566E-01 1.822E-01 2.045E-01 2.224E-01 2.347E-01 2.393E-01  
 0.600C C.00CE+00 2.962E-C2 5.982E-02 8.716E-02 1.142E-01 1.394E-01 1.622E-01 1.820E-01 1.980E-01 2.090E-01 2.130E-01  
 1.200C C.00CE+00 2.608E-C2 5.178E-02 7.673E-02 1.005E-01 1.227E-01 1.428E-01 1.602E-01 1.743E-01 1.839E-01 1.873E-01  
 1.800C C.00CE+00 2.263E-C2 4.494E-02 6.660E-02 8.724E-02 1.065E-01 1.239E-01 1.391E-01 1.513E-01 1.597E-01 1.628E-01  
 2.400C C.00CE+00 1.928E-C2 3.829E-02 5.673E-02 7.432E-02 9.073E-02 1.056E-01 1.185E-01 1.289E-01 1.360E-01 1.387E-01  
 3.000C C.00CE+00 1.601E-C2 3.179E-02 4.711E-02 6.171E-02 7.533E-02 8.767E-02 9.838E-02 1.070E-01 1.129E-01 1.151E-01  
 3.600C C.00CE+00 1.281E-C2 2.543E-02 3.768E-02 4.936E-02 6.026E-02 7.013E-02 7.869E-02 8.559E-02 9.033E-02 9.210E-02  
 4.200C C.00CE+00 9.658E-C3 1.918E-02 2.842E-02 3.722E-02 4.544E-02 5.289E-02 5.934E-02 6.454E-02 6.812E-02 6.945E-02  
 4.800C C.00CE+00 6.549E-C3 1.301E-02 1.927E-02 2.524E-02 3.082E-02 3.587E-02 4.024E-02 4.377E-02 4.620E-02 4.710E-02  
 5.400C C.00CE+00 3.468E-C3 6.887E-03 1.021E-02 1.337E-02 1.632E-02 1.899E-02 2.131E-02 2.318E-02 2.447E-02 2.494E-02  
 6.000C C.00CE+00 4.011E-C4 7.964E-04 1.180E-03 1.546E-03 1.887E-03 2.196E-03 2.465E-03 2.681E-03 2.829E-03 2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = 7.38

X\Z= C.00E+00 1.00E-01 2.00E-01 3.00E-01 4.00E-01 5.00E-01 6.00E-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00  
 -6.000C C.00CE+00 5.911E-C2 1.174E-01 1.739E-01 2.278E-01 2.781E-01 3.237E-01 3.632E-01 3.950E-01 4.169E-01 4.250E-01  
 -5.400C C.00CE+00 5.950E-C2 1.131E-01 1.751E-01 2.293E-01 2.800E-01 3.258E-01 3.656E-01 3.976E-01 4.197E-01 4.279E-01  
 -4.800C C.00CE+00 5.913E-C2 1.175E-01 1.740E-01 2.280E-01 2.783E-01 3.239E-01 3.635E-01 3.953E-01 4.172E-01 4.254E-01  
 -4.200C C.00CE+00 5.773E-C2 1.146E-01 1.698E-01 2.225E-01 2.716E-01 3.161E-01 3.546E-01 3.857E-01 4.071E-01 4.151E-01  
 -3.600C C.00CE+00 5.528E-C2 1.098E-01 1.627E-01 2.131E-01 2.601E-01 3.027E-01 3.397E-01 3.695E-01 3.899E-01 3.976E-01  
 -3.000C C.00CE+00 5.213E-C2 1.035E-01 1.534E-01 2.009E-01 2.453E-01 2.855E-01 3.203E-01 3.484E-01 3.677E-01 3.749E-01  
 -2.400C C.00CE+00 4.855E-C2 9.641E-02 1.429E-01 1.871E-01 2.285E-01 2.659E-01 2.983E-01 3.245E-01 3.425E-01 3.492E-01  
 -1.800C C.00CE+00 4.471E-C2 8.869E-02 1.317E-01 1.725E-01 2.106E-01 2.451E-01 2.751E-01 2.992E-01 3.158E-01 3.219E-01  
 -1.200C C.00CE+00 4.092E-C2 8.125E-02 1.204E-01 1.577E-01 1.925E-01 2.241E-01 2.514E-01 2.735E-01 2.886E-01 2.942E-01  
 -0.600C C.00CE+00 3.709E-C2 7.366E-02 1.091E-01 1.430E-01 1.745E-01 2.031E-01 2.279E-01 2.479E-01 2.616E-01 2.668E-01  
 0.000C C.00CE+00 3.345E-C2 6.621E-02 9.811E-02 1.285E-01 1.569E-01 1.826E-01 2.049E-01 2.228E-01 2.352E-01 2.398E-01  
 0.600C C.00CE+00 2.969E-C2 5.896E-02 8.736E-02 1.144E-01 1.397E-01 1.626E-01 1.824E-01 1.984E-01 2.094E-01 2.155E-01  
 1.200C C.00CE+00 2.614E-C2 5.191E-02 7.691E-02 1.008E-01 1.230E-01 1.431E-01 1.606E-01 1.747E-01 1.844E-01 1.880E-01  
 1.800C C.00CE+00 2.269E-C2 4.505E-02 6.676E-02 8.746E-02 1.068E-01 1.242E-01 1.394E-01 1.516E-01 1.600E-01 1.632E-01  
 2.400C C.00CE+00 1.933E-C2 3.833E-02 5.687E-02 7.451E-02 9.095E-02 1.059E-01 1.188E-01 1.292E-01 1.363E-01 1.390E-01  
 3.000C C.00CE+00 1.605E-C2 3.187E-02 4.722E-02 6.186E-02 7.552E-02 8.789E-02 9.862E-02 1.073E-01 1.132E-01 1.154E-01  
 3.600C C.00CE+00 1.284E-C2 2.545E-02 3.778E-02 4.949E-02 6.041E-02 7.030E-02 7.889E-02 8.580E-02 9.056E-02 9.233E-02



4.200C C.00CE+00 9.681E-03 1.922E-02 2.849E-02 3.732E-02 4.555E-02 5.302E-02 5.949E-02 6.470E-02 6.829E-02 6.962E-02  
 4.800C C.00CE+00 9.565E-03 1.304E-02 1.932E-02 2.531E-02 3.089E-02 3.595E-02 4.034E-02 4.388E-02 4.631E-02 4.721E-02  
 5.400C C.00CE+00 3.476E-03 6.903E-03 1.023E-02 1.34CE-02 1.636E-02 1.904E-02 2.136E-02 2.323E-02 2.452E-02 2.500E-02  
 6.000C C.00CE+00 4.011E-04 7.964E-04 1.180E-03 1.546E-03 1.887E-03 2.196E-03 2.465E-03 2.681E-03 2.829E-03 2.884E-03

# INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = 4.92

X\Z=	C.00E+00	1.0CE-01	2.00E-01	3.0CE-01	4.00E-01	5.0CE-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.000C	C.00CE+00	5.801E-02	1.152E-01	1.707E-01	2.236E-01	2.730E-01	3.177E-01	3.565E-01	3.877E-01	4.092E-01	4.172E-01
-5.400C	C.00CE+00	5.845E-02	1.161E-01	1.720E-01	2.253E-01	2.750E-01	3.201E-01	3.592E-01	3.906E-01	4.123E-01	4.203E-01
-4.800C	C.00CE+00	5.833E-02	1.158E-01	1.716E-01	2.248E-01	2.745E-01	3.194E-01	3.584E-01	3.898E-01	4.114E-01	4.195E-01
-4.200C	C.00CE+00	5.717E-02	1.135E-01	1.682E-01	2.204E-01	2.690E-01	3.131E-01	3.513E-01	3.821E-01	4.032E-01	4.111E-01
-3.600C	C.00CE+00	5.497E-02	1.092E-01	1.617E-01	2.119E-01	2.587E-01	3.010E-01	3.378E-01	3.674E-01	3.878E-01	3.953E-01
-3.000C	C.00CE+00	5.199E-02	1.032E-01	1.530E-01	2.004E-01	2.446E-01	2.847E-01	3.195E-01	3.475E-01	3.668E-01	3.739E-01
-2.400C	C.00CE+00	4.853E-02	9.636E-02	1.428E-01	1.870E-01	2.283E-01	2.657E-01	2.982E-01	3.243E-01	3.423E-01	3.490E-01
-1.800C	C.00CE+00	4.480E-02	8.896E-02	1.318E-01	1.727E-01	2.108E-01	2.453E-01	2.753E-01	2.994E-01	3.160E-01	3.222E-01
-1.200C	C.00CE+00	4.099E-02	8.139E-02	1.206E-01	1.580E-01	1.929E-01	2.245E-01	2.519E-01	2.739E-01	2.891E-01	2.948E-01
-0.600C	C.00CE+00	3.718E-02	7.383E-02	1.094E-01	1.433E-01	1.749E-01	2.036E-01	2.285E-01	2.485E-01	2.623E-01	2.674E-01
0.000C	C.00CE+00	3.343E-02	6.639E-02	9.838E-02	1.289E-01	1.573E-01	1.831E-01	2.054E-01	2.234E-01	2.358E-01	2.404E-01
0.600C	C.00CE+00	2.978E-02	5.913E-02	8.762E-02	1.148E-01	1.401E-01	1.631E-01	1.830E-01	1.990E-01	2.100E-01	2.141E-01
1.200C	C.00CE+00	2.622E-02	5.207E-02	7.715E-02	1.011E-01	1.234E-01	1.436E-01	1.611E-01	1.752E-01	1.850E-01	1.886E-01
1.800C	C.00CE+00	2.276E-02	4.520E-02	6.697E-02	8.773E-02	1.071E-01	1.246E-01	1.399E-01	1.521E-01	1.605E-01	1.637E-01
2.400C	C.00CE+00	1.939E-02	3.850E-02	5.705E-02	7.474E-02	9.124E-02	1.062E-01	1.191E-01	1.296E-01	1.368E-01	1.394E-01
3.000C	C.00CE+00	1.610E-02	3.197E-02	4.737E-02	6.206E-02	7.576E-02	8.817E-02	9.893E-02	1.076E-01	1.136E-01	1.158E-01
3.600C	C.00CE+00	1.288E-02	2.557E-02	3.789E-02	4.964E-02	6.060E-02	7.053E-02	7.914E-02	8.607E-02	9.085E-02	9.262E-02
4.200C	C.00CE+00	9.712E-03	1.928E-02	2.857E-02	3.743E-02	4.570E-02	5.318E-02	5.967E-02	6.490E-02	6.850E-02	6.984E-02
4.800C	C.00CE+00	6.585E-03	1.308E-02	1.938E-02	2.538E-02	3.099E-02	3.606E-02	4.046E-02	4.401E-02	4.645E-02	4.736E-02
5.400C	C.00CE+00	3.486E-03	6.923E-03	1.026E-02	1.344E-02	1.640E-02	1.909E-02	2.142E-02	2.330E-02	2.459E-02	2.507E-02
6.000C	C.00CE+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

# INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = 2.46

X\Z=	C.00E+00	1.0CE-01	2.00E-01	3.0CE-01	4.00E-01	5.0CE-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.000C	C.00CE+00	5.666E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.103E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-5.400C	C.00CE+00	5.718E-02	1.135E-01	1.682E-01	2.204E-01	2.691E-01	3.131E-01	3.514E-01	3.822E-01	4.033E-01	4.112E-01
-4.800C	C.00CE+00	5.735E-02	1.138E-01	1.687E-01	2.218E-01	2.698E-01	3.140E-01	3.523E-01	3.832E-01	4.044E-01	4.123E-01
-4.200C	C.00CE+00	5.650E-02	1.122E-01	1.662E-01	2.178E-01	2.659E-01	3.094E-01	3.472E-01	3.776E-01	3.985E-01	4.063E-01
-3.600C	C.00CE+00	5.459E-02	1.084E-01	1.606E-01	2.104E-01	2.569E-01	2.990E-01	3.354E-01	3.649E-01	3.851E-01	3.927E-01
-3.000C	C.00CE+00	5.182E-02	1.029E-01	1.525E-01	1.997E-01	2.438E-01	2.838E-01	3.184E-01	3.463E-01	3.655E-01	3.727E-01
-2.400C	C.00CE+00	4.849E-02	9.628E-02	1.427E-01	1.869E-01	2.282E-01	2.655E-01	2.979E-01	3.241E-01	3.420E-01	3.487E-01
-1.800C	C.00CE+00	4.484E-02	8.905E-02	1.319E-01	1.729E-01	2.110E-01	2.456E-01	2.755E-01	2.997E-01	3.163E-01	3.225E-01
-1.200C	C.00CE+00	4.107E-02	8.156E-02	1.208E-01	1.583E-01	1.933E-01	2.249E-01	2.524E-01	2.745E-01	2.897E-01	2.954E-01
-0.600C	C.00CE+00	3.728E-02	7.403E-02	1.097E-01	1.437E-01	1.754E-01	2.042E-01	2.291E-01	2.492E-01	2.630E-01	2.681E-01
0.000C	C.00CE+00	3.354E-02	6.66CE-02	9.869E-02	1.292E-01	1.578E-01	1.836E-01	2.061E-01	2.247E-01	2.366E-01	2.419E-01
0.600C	C.00CE+00	2.988E-02	5.934E-02	8.792E-02	1.152E-01	1.406E-01	1.636E-01	1.836E-01	1.997E-01	2.108E-01	2.149E-01
1.200C	C.00CE+00	2.632E-02	5.226E-02	7.743E-02	1.014E-01	1.238E-01	1.441E-01	1.617E-01	1.759E-01	1.856E-01	1.892E-01
1.800C	C.00CE+00	2.285E-02	4.536E-02	6.722E-02	8.806E-02	1.075E-01	1.251E-01	1.404E-01	1.527E-01	1.611E-01	1.643E-01
2.400C	C.00CE+00	1.946E-02	3.865E-02	5.727E-02	7.502E-02	9.158E-02	1.066E-01	1.196E-01	1.301E-01	1.373E-01	1.400E-01
3.000C	C.00CE+00	1.616E-02	3.209E-02	4.755E-02	6.230E-02	7.605E-02	8.850E-02	9.931E-02	1.060E-01	1.140E-01	1.162E-01

3.600C	C.00CE+00	1.293E-02	2.567E-02	3.804E-02	4.983E-02	6.083E-02	7.079E-02	7.943E-02	8.640E-02	9.119E-02	9.297E-02
4.200C	C.00CE+00	9.748E-03	1.936E-02	2.868E-02	3.757E-02	4.587E-02	5.335E-02	5.990E-02	6.515E-02	6.876E-02	7.010E-02
4.800C	C.00CE+00	6.609E-03	1.312E-02	1.945E-02	2.548E-02	3.110E-02	3.619E-02	4.041E-02	4.347E-02	4.533E-02	4.622E-02
5.400C	C.00CE+00	3.492E-03	6.946E-03	1.029E-02	1.348E-02	1.646E-02	1.916E-02	2.150E-02	2.338E-02	2.468E-02	2.516E-02
6.000C	C.00CE+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = C.00

X1Z=	C.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.000C	C.00CE+00	5.575E-02	1.107E-01	1.640E-01	2.149E-01	2.623E-01	3.053E-01	3.426E-01	3.726E-01	3.933E-01	4.009E-01
-5.400C	C.00CE+00	5.633E-02	1.119E-01	1.658E-01	2.171E-01	2.651E-01	3.085E-01	3.461E-01	3.765E-01	3.974E-01	4.051E-01
-4.800C	C.00CE+00	5.667E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.101E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-4.200C	C.00CE+00	5.606E-02	1.113E-01	1.649E-01	2.161E-01	2.638E-01	3.075E-01	3.444E-01	3.746E-01	3.954E-01	4.031E-01
-3.600C	C.00CE+00	5.434E-02	1.079E-01	1.599E-01	2.095E-01	2.557E-01	2.976E-01	3.339E-01	3.632E-01	3.833E-01	3.908E-01
-3.000C	C.00CE+00	5.171E-02	1.027E-01	1.522E-01	1.993E-01	2.433E-01	2.832E-01	3.178E-01	3.456E-01	3.648E-01	3.719E-01
-2.400C	C.00CE+00	4.847E-02	9.625E-02	1.426E-01	1.868E-01	2.281E-01	2.654E-01	2.978E-01	3.239E-01	3.419E-01	3.486E-01
-1.800C	C.00CE+00	4.488E-02	8.912E-02	1.321E-01	1.730E-01	2.112E-01	2.458E-01	2.758E-01	3.000E-01	3.166E-01	3.228E-01
-1.200C	C.00CE+00	4.114E-02	8.169E-02	1.210E-01	1.586E-01	1.936E-01	2.253E-01	2.528E-01	2.749E-01	2.902E-01	2.958E-01
-0.600C	C.00CE+00	3.736E-02	7.419E-02	1.099E-01	1.440E-01	1.758E-01	2.045E-01	2.295E-01	2.497E-01	2.636E-01	2.687E-01
0.000C	C.00CE+00	3.363E-02	6.677E-02	9.894E-02	1.296E-01	1.582E-01	1.841E-01	2.066E-01	2.247E-01	2.372E-01	2.418E-01
0.600C	C.00CE+00	2.639E-02	5.240E-02	7.765E-02	1.017E-01	1.242E-01	1.445E-01	1.622E-01	1.764E-01	1.862E-01	1.898E-01
1.200C	C.00CE+00	2.291E-02	4.550E-02	6.741E-02	8.831E-02	1.078E-01	1.253E-01	1.408E-01	1.531E-01	1.616E-01	1.648E-01
1.800C	C.00CE+00	1.952E-02	3.876E-02	5.744E-02	7.524E-02	9.185E-02	1.069E-01	1.199E-01	1.305E-01	1.377E-01	1.404E-01
2.400C	C.00CE+00	1.621E-02	3.219E-02	4.769E-02	6.248E-02	7.627E-02	8.876E-02	9.960E-02	1.083E-01	1.143E-01	1.166E-01
3.000C	C.00CE+00	1.297E-02	2.575E-02	3.815E-02	4.998E-02	6.101E-02	7.100E-02	7.967E-02	8.665E-02	9.146E-02	9.324E-02
3.600C	C.00CE+00	9.776E-03	1.941E-02	2.876E-02	3.768E-02	4.600E-02	5.354E-02	6.007E-02	6.534E-02	6.896E-02	7.030E-02
4.200C	C.00CE+00	8.623E-03	1.316E-02	1.950E-02	2.555E-02	3.119E-02	3.630E-02	4.073E-02	4.430E-02	4.675E-02	4.767E-02
4.800C	C.00CE+00	7.508E-03	6.965E-03	1.032E-02	1.352E-02	1.650E-02	1.921E-02	2.155E-02	2.344E-02	2.474E-02	2.523E-02
5.400C	C.00CE+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = -2.46

X1Z=	C.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.000C	C.00CE+00	5.704E-02	1.133E-01	1.678E-01	2.198E-01	2.684E-01	3.123E-01	3.505E-01	3.812E-01	4.023E-01	4.102E-01
-5.400C	C.00CE+00	5.751E-02	1.142E-01	1.692E-01	2.217E-01	2.706E-01	3.149E-01	3.534E-01	3.844E-01	4.057E-01	4.136E-01
-4.800C	C.00CE+00	5.758E-02	1.143E-01	1.694E-01	2.219E-01	2.709E-01	3.152E-01	3.538E-01	3.848E-01	4.062E-01	4.141E-01
-4.200C	C.00CE+00	5.666E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.103E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-3.600C	C.00CE+00	5.468E-02	1.086E-01	1.609E-01	2.108E-01	2.573E-01	2.994E-01	3.305E-01	3.544E-01	3.857E-01	3.932E-01
-3.000C	C.00CE+00	5.186E-02	1.030E-01	1.526E-01	1.999E-01	2.440E-01	2.845E-01	3.186E-01	3.466E-01	3.658E-01	3.729E-01
-2.400C	C.00CE+00	4.849E-02	9.629E-02	1.427E-01	1.869E-01	2.282E-01	2.655E-01	2.900E-01	3.241E-01	3.420E-01	3.487E-01
-1.800C	C.00CE+00	4.483E-02	8.902E-02	1.319E-01	1.728E-01	2.109E-01	2.455E-01	2.755E-01	2.996E-01	3.162E-01	3.224E-01
-1.200C	C.00CE+00	4.105E-02	8.151E-02	1.208E-01	1.582E-01	1.931E-01	2.246E-01	2.522E-01	2.743E-01	2.895E-01	2.952E-01
-0.600C	C.00CE+00	3.725E-02	7.397E-02	1.096E-01	1.436E-01	1.753E-01	2.046E-01	2.289E-01	2.490E-01	2.628E-01	2.679E-01
0.000C	C.00CE+00	3.351E-02	6.654E-02	9.860E-02	1.292E-01	1.577E-01	1.833E-01	2.095E-01	2.340E-01	2.564E-01	2.640E-01
0.600C	C.00CE+00	2.985E-02	5.928E-02	8.784E-02	1.151E-01	1.405E-01	1.635E-01	1.834E-01	1.995E-01	2.106E-01	2.147E-01
1.200C	C.00CE+00	2.629E-02	5.220E-02	7.735E-02	1.013E-01	1.237E-01	1.440E-01	1.615E-01	1.757E-01	1.854E-01	1.891E-01
1.800C	C.00CE+00	2.282E-02	4.532E-02	6.715E-02	8.797E-02	1.074E-01	1.250E-01	1.402E-01	1.525E-01	1.610E-01	1.641E-01
2.400C	C.00CE+00	1.944E-02	3.861E-02	5.721E-02	7.495E-02	9.149E-02	1.065E-01	1.195E-01	1.299E-01	1.372E-01	1.398E-01



3.0000 C.000E+00 1.615E-02 3.206E-02 4.750E-02 6.223E-02 7.597E-02 8.841E-02 9.921E-02 1.079E-01 1.139E-01 1.161E-01  
3.6000 C.000E+00 1.291E-02 2.564E-02 3.800E-02 4.978E-02 6.077E-02 7.033E-02 7.935E-02 8.631E-02 9.109E-02 9.287E-02  
4.2000 C.000E+00 9.738E-03 1.934E-02 2.865E-02 3.734E-02 4.582E-02 5.373E-02 6.132E-02 6.869E-02 7.508E-02 7.003E-02  
4.8000 C.000E+00 6.603E-03 1.311E-02 1.943E-02 2.545E-02 3.107E-02 3.616E-02 4.057E-02 4.413E-02 4.657E-02 4.748E-02  
5.4000 C.000E+00 3.495E-03 6.940E-03 1.028E-02 1.347E-02 1.645E-02 1.914E-02 2.148E-02 2.336E-02 2.465E-02 2.513E-02  
6.0000 C.000E+00 4.011E-04 7.964E-04 1.180E-03 1.546E-03 1.887E-03 2.196E-03 2.465E-03 2.681E-03 2.829E-03 2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = -4.92

X\Z= C.00E+00 1.00E-01 2.00E-01 3.00E-01 4.00E-01 5.00E-01 6.00E-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00  
-6.0000 C.000E+00 5.841E-02 1.160E-01 1.719E-01 2.251E-01 2.748E-01 3.199E-01 3.589E-01 3.904E-01 4.120E-01 4.201E-01  
-5.4000 C.000E+00 5.879E-02 1.167E-01 1.730E-01 2.266E-01 2.766E-01 3.219E-01 3.613E-01 3.929E-01 4.147E-01 4.228E-01  
-4.8000 C.000E+00 5.857E-02 1.163E-01 1.723E-01 2.258E-01 2.756E-01 3.208E-01 3.599E-01 3.915E-01 4.132E-01 4.212E-01  
-4.2000 C.000E+00 5.732E-02 1.138E-01 1.687E-01 2.209E-01 2.697E-01 3.139E-01 3.522E-01 3.831E-01 4.043E-01 4.122E-01  
-3.6000 C.000E+00 5.505E-02 1.093E-01 1.620E-01 2.122E-01 2.590E-01 3.015E-01 3.383E-01 3.679E-01 3.883E-01 3.959E-01  
-3.0000 C.000E+00 5.202E-02 1.033E-01 1.531E-01 2.005E-01 2.448E-01 2.849E-01 3.197E-01 3.477E-01 3.670E-01 3.741E-01  
-2.4000 C.000E+00 4.853E-02 9.635E-02 1.428E-01 1.870E-01 2.283E-01 2.657E-01 2.982E-01 3.243E-01 3.423E-01 3.490E-01  
-1.8000 C.000E+00 4.478E-02 8.893E-02 1.318E-01 1.726E-01 2.107E-01 2.452E-01 2.752E-01 2.993E-01 3.159E-01 3.221E-01  
-1.2000 C.000E+00 3.715E-02 7.371E-02 1.093E-01 1.432E-01 1.748E-01 2.034E-01 2.283E-01 2.483E-01 2.620E-01 2.672E-01  
-0.6000 C.000E+00 3.340E-02 6.633E-02 9.828E-02 1.288E-01 1.572E-01 1.829E-01 2.052E-01 2.232E-01 2.356E-01 2.402E-01  
0.0000 C.000E+00 2.975E-02 5.907E-02 8.753E-02 1.147E-01 1.400E-01 1.629E-01 1.828E-01 1.988E-01 2.098E-01 2.139E-01  
1.2000 C.000E+00 2.619E-02 5.201E-02 7.707E-02 1.010E-01 1.232E-01 1.434E-01 1.609E-01 1.751E-01 1.848E-01 1.884E-01  
1.8000 C.000E+00 2.274E-02 4.515E-02 6.690E-02 8.764E-02 1.070E-01 1.245E-01 1.397E-01 1.520E-01 1.604E-01 1.635E-01  
2.4000 C.000E+00 1.937E-02 3.846E-02 5.699E-02 7.466E-02 9.114E-02 1.061E-01 1.190E-01 1.295E-01 1.366E-01 1.393E-01  
3.0000 C.000E+00 1.608E-02 3.194E-02 4.732E-02 6.200E-02 7.568E-02 8.808E-02 9.883E-02 1.075E-01 1.135E-01 1.157E-01  
3.6000 C.000E+00 1.287E-02 2.555E-02 3.785E-02 4.959E-02 6.054E-02 7.045E-02 7.905E-02 8.598E-02 9.075E-02 9.252E-02  
4.2000 C.000E+00 9.702E-03 1.926E-02 2.855E-02 3.736E-02 4.565E-02 5.313E-02 5.961E-02 6.484E-02 6.843E-02 6.977E-02  
4.8000 C.000E+00 6.579E-03 1.306E-02 1.936E-02 2.536E-02 3.095E-02 3.603E-02 4.042E-02 4.397E-02 4.640E-02 4.731E-02  
5.4000 C.000E+00 3.483E-03 6.916E-03 1.025E-02 1.343E-02 1.639E-02 1.907E-02 2.140E-02 2.328E-02 2.457E-02 2.505E-02  
6.0000 C.000E+00 4.011E-04 7.964E-04 1.180E-03 1.546E-03 1.887E-03 2.196E-03 2.465E-03 2.681E-03 2.829E-03 2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLCT AT LOCATION X = -7.38

X\Z= C.00E+00 1.00E-01 2.00E-01 3.00E-01 4.00E-01 5.00E-01 6.00E-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00  
-6.0000 C.000E+00 5.952E-02 1.182E-01 1.751E-01 2.294E-01 2.801E-01 3.259E-01 3.657E-01 3.978E-01 4.198E-01 4.280E-01  
-5.4000 C.000E+00 5.984E-02 1.188E-01 1.761E-01 2.307E-01 2.816E-01 3.277E-01 3.677E-01 3.999E-01 4.221E-01 4.303E-01  
-4.8000 C.000E+00 5.939E-02 1.179E-01 1.747E-01 2.289E-01 2.795E-01 3.252E-01 3.649E-01 3.969E-01 4.189E-01 4.271E-01  
-4.2000 C.000E+00 5.786E-02 1.149E-01 1.702E-01 2.230E-01 2.723E-01 3.168E-01 3.555E-01 3.867E-01 4.081E-01 4.161E-01  
-3.6000 C.000E+00 5.536E-02 1.099E-01 1.629E-01 2.134E-01 2.605E-01 3.031E-01 3.401E-01 3.699E-01 3.905E-01 3.981E-01  
-3.0000 C.000E+00 5.216E-02 1.036E-01 1.535E-01 2.010E-01 2.454E-01 2.856E-01 3.205E-01 3.486E-01 3.679E-01 3.751E-01  
-2.4000 C.000E+00 4.855E-02 9.640E-02 1.428E-01 1.871E-01 2.284E-01 2.659E-01 2.983E-01 3.245E-01 3.424E-01 3.491E-01  
-1.8000 C.000E+00 4.475E-02 8.885E-02 1.317E-01 1.725E-01 2.105E-01 2.450E-01 2.749E-01 2.990E-01 3.156E-01 3.218E-01  
-1.2000 C.000E+00 4.089E-02 8.119E-02 1.192E-01 1.576E-01 1.924E-01 2.239E-01 2.512E-01 2.733E-01 2.884E-01 2.940E-01  
-0.6000 C.000E+00 3.706E-02 7.359E-02 1.090E-01 1.429E-01 1.744E-01 2.030E-01 2.277E-01 2.477E-01 2.614E-01 2.665E-01  
0.0000 C.000E+00 3.331E-02 6.615E-02 9.802E-02 1.284E-01 1.567E-01 1.824E-01 2.047E-01 2.226E-01 2.350E-01 2.396E-01  
0.6000 C.000E+00 2.966E-02 5.890E-02 8.727E-02 1.143E-01 1.396E-01 1.624E-01 1.823E-01 1.982E-01 2.092E-01 2.133E-01  
1.2000 C.000E+00 2.611E-02 5.185E-02 7.683E-02 1.007E-01 1.229E-01 1.430E-01 1.605E-01 1.745E-01 1.842E-01 1.878E-01  
1.8000 C.000E+00 2.267E-02 4.501E-02 6.669E-02 8.736E-02 1.066E-01 1.241E-01 1.393E-01 1.515E-01 1.599E-01 1.630E-01



2.4000	C.000E+00	1.931E-C2	3.834E-02	5.681E-02	7.443E-02	9.086E-02	1.057E-01	1.186E-C1	1.290E-01	1.362E-01	1.389E-01
3.0000	C.000E+00	1.603E-C2	3.184E-02	4.717E-02	6.180E-02	7.544E-02	8.780E-02	9.852E-C2	1.072E-01	1.131E-01	1.153E-01
3.6000	C.000E+00	1.283E-C2	2.547E-02	3.774E-02	4.943E-02	6.035E-02	7.023E-02	7.830E-C2	8.571E-02	9.046E-C2	9.223E-02
4.2000	C.000E+00	9.671E-C3	1.922E-02	2.846E-02	3.728E-02	4.551E-02	5.296E-02	5.943E-C2	6.464E-02	6.822E-02	6.955E-02
4.8000	C.000E+00	6.559E-C3	1.302E-02	1.930E-02	2.528E-02	3.086E-02	3.592E-02	4.030E-C2	4.385E-02	4.626E-02	4.716E-02
5.4000	C.000E+00	3.473E-C3	6.896E-03	1.022E-02	1.339E-02	1.634E-02	1.902E-02	2.134E-C2	2.321E-02	2.450E-02	2.498E-02
6.0000	C.000E+00	4.011E-C4	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = -9.84

X\Z=	C.000E+00	1.00E-01	2.00E-01	3.00E-C1	4.00E-01	5.00E-C1	6.00E-01	7.00E-01	8.00E-01	9.00E-C1	1.00E+00
-6.0000	C.000E+00	6.033E-C2	1.198E-01	1.775E-01	2.326E-01	2.839E-01	3.304E-01	3.707E-C1	4.032E-01	4.256E-01	4.339E-01
-5.4000	C.000E+00	6.064E-C2	1.204E-01	1.784E-01	2.337E-01	2.853E-01	3.321E-01	3.726E-01	4.053E-01	4.277E-01	4.361E-01
-4.8000	C.000E+00	6.002E-C2	1.192E-01	1.766E-01	2.314E-01	2.824E-01	3.287E-01	3.688E-01	4.011E-01	4.234E-01	4.316E-01
-4.2000	C.000E+00	5.828E-C2	1.157E-01	1.715E-01	2.246E-01	2.742E-01	3.191E-01	3.581E-01	3.895E-01	4.111E-C1	4.191E-01
-3.6000	C.000E+00	5.559E-C2	1.104E-01	1.636E-01	2.143E-01	2.616E-01	3.044E-01	3.416E-01	3.715E-01	3.921E-01	3.998E-01
-3.0000	C.000E+00	5.226E-02	1.038E-01	1.538E-01	2.014E-01	2.459E-01	2.862E-01	3.211E-C1	3.493E-01	3.686E-01	3.758E-01
-2.4000	C.000E+00	4.857E-02	9.644E-02	1.429E-01	1.872E-01	2.285E-01	2.660E-01	2.984E-01	3.246E-01	3.426E-01	3.493E-01
-1.8000	C.000E+00	4.471E-C2	8.879E-02	1.316E-01	1.723E-01	2.104E-01	2.449E-01	2.747E-01	2.988E-01	3.154E-01	3.216E-01
-1.2000	C.000E+00	4.083E-02	8.108E-02	1.201E-01	1.574E-01	1.921E-01	2.236E-01	2.509E-01	2.729E-01	2.880E-01	2.936E-01
-0.6000	C.000E+00	3.699E-02	7.346E-02	1.088E-01	1.426E-01	1.741E-01	2.026E-01	2.273E-01	2.472E-01	2.609E-01	2.660E-01
0.0000	C.000E+00	3.324E-02	6.601E-02	9.781E-02	1.261E-01	1.564E-01	1.820E-01	2.043E-01	2.222E-01	2.345E-01	2.391E-01
0.6000	C.000E+00	2.959E-C2	5.876E-02	8.707E-02	1.141E-01	1.392E-01	1.621E-01	1.818E-C1	1.978E-01	2.087E-01	2.128E-01
1.2000	C.000E+00	2.605E-C2	5.173E-02	7.665E-02	1.004E-01	1.226E-01	1.427E-01	1.601E-01	1.741E-01	1.838E-01	1.873E-01
1.8000	C.000E+00	2.261E-C2	4.490E-02	6.653E-02	8.715E-02	1.064E-01	1.238E-01	1.389E-C1	1.511E-01	1.595E-01	1.626E-01
2.4000	C.000E+00	1.925E-02	3.825E-02	5.667E-02	7.424E-02	9.063E-02	1.055E-01	1.184E-C1	1.287E-01	1.339E-01	1.385E-01
3.0000	C.000E+00	1.599E-C2	3.176E-02	4.706E-02	6.165E-02	7.525E-02	8.758E-02	9.827E-02	1.069E-01	1.128E-01	1.150E-01
3.6000	C.000E+00	1.279E-C2	2.540E-02	3.764E-02	4.931E-02	6.020E-02	7.006E-02	7.861E-C2	8.550E-02	9.024E-02	9.200E-02
4.2000	C.000E+00	9.648E-C3	1.916E-02	2.839E-02	3.719E-02	4.540E-02	5.283E-02	5.928E-02	6.448E-02	6.805E-02	6.938E-02
4.8000	C.000E+00	6.543E-C3	1.299E-02	1.925E-02	2.522E-02	3.079E-02	3.583E-02	4.020E-02	4.373E-02	4.615E-02	4.705E-02
5.4000	C.000E+00	3.465E-C3	6.881E-03	1.020E-02	1.336E-02	1.630E-02	1.898E-02	2.129E-C2	2.316E-02	2.444E-02	2.492E-02
6.0000	C.000E+00	4.011E-C4	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-C3	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X =-12.30

X\Z=	C.000E+00	1.00E-01	2.00E-01	3.00E-C1	4.00E-01	5.00E-C1	6.00E-01	7.00E-C1	8.00E-01	9.00E-01	1.00E+00
-6.0000	C.000E+00	6.083E-C2	1.208E-01	1.790E-C1	2.345E-01	2.863E-01	3.332E-01	3.739E-C1	4.067E-01	4.292E-01	4.376E-01
-5.4000	C.000E+00	6.119E-C2	1.215E-01	1.800E-01	2.358E-01	2.879E-01	3.351E-01	3.760E-01	4.089E-01	4.316E-01	4.400E-01
-4.8000	C.000E+00	6.047E-C2	1.201E-01	1.779E-01	2.331E-01	2.845E-01	3.311E-01	3.716E-C1	4.041E-01	4.265E-01	4.349E-01
-4.2000	C.000E+00	5.859E-C2	1.163E-01	1.724E-01	2.258E-01	2.756E-01	3.208E-01	3.600E-01	3.915E-01	4.132E-01	4.213E-01
-3.6000	C.000E+00	5.575E-C2	1.107E-01	1.641E-01	2.149E-01	2.624E-01	3.054E-01	3.426E-01	3.727E-01	3.933E-01	4.010E-01
-3.0000	C.000E+00	5.234E-C2	1.039E-01	1.540E-01	2.017E-01	2.463E-01	2.866E-01	3.216E-01	3.498E-01	3.692E-01	3.764E-01
-2.4000	C.000E+00	4.858E-C2	9.647E-02	1.429E-01	1.873E-01	2.286E-01	2.660E-01	2.984E-01	3.247E-01	3.427E-01	3.494E-01
-1.8000	C.000E+00	4.470E-C2	8.875E-02	1.315E-01	1.723E-01	2.103E-01	2.448E-01	2.746E-01	2.987E-01	3.153E-01	3.214E-01
-1.2000	C.000E+00	4.079E-C2	8.100E-02	1.200E-01	1.572E-01	1.919E-01	2.234E-01	2.507E-01	2.726E-01	2.877E-01	2.934E-01
-0.6000	C.000E+00	3.695E-C2	7.337E-02	1.087E-01	1.424E-01	1.739E-01	2.023E-01	2.270E-01	2.469E-01	2.606E-01	2.657E-01
0.0000	C.000E+00	3.319E-C2	6.591E-02	9.767E-02	1.279E-01	1.562E-01	1.818E-01	2.040E-01	2.218E-01	2.341E-01	2.387E-01
0.6000	C.000E+00	2.955E-C2	5.867E-02	8.694E-02	1.139E-01	1.390E-01	1.618E-01	1.816E-01	1.975E-01	2.084E-01	2.125E-01
1.2000	C.000E+00	2.601E-C2	5.164E-02	7.652E-02	1.002E-01	1.224E-01	1.424E-01	1.598E-01	1.738E-01	1.835E-01	1.870E-01

1.8000	C.000E+00	2.257E-02	4.482E-02	6.641E-02	8.700E-02	1.062E-01	1.236E-01	1.387E-01	1.508E-01	1.592E-01	1.623E-01
2.4000	C.000E+00	1.923E-02	3.818E-02	5.657E-02	7.411E-02	9.047E-02	1.053E-01	1.181E-01	1.285E-01	1.356E-01	1.383E-01
3.0000	C.000E+00	1.597E-02	3.170E-02	4.698E-02	6.154E-02	7.512E-02	8.743E-02	9.810E-02	1.067E-01	1.126E-01	1.148E-01
3.6000	C.000E+00	1.277E-02	2.536E-02	3.758E-02	4.923E-02	6.009E-02	6.994E-02	7.847E-02	8.535E-02	9.008E-02	9.184E-02
4.2000	C.000E+00	9.631E-03	1.912E-02	2.834E-02	3.712E-02	4.532E-02	5.274E-02	5.918E-02	6.437E-02	6.793E-02	6.926E-02
4.8000	C.000E+00	6.532E-03	1.297E-02	1.922E-02	2.518E-02	3.073E-02	3.577E-02	4.013E-02	4.365E-02	4.607E-02	4.697E-02
5.4000	C.000E+00	3.460E-03	6.870E-03	1.018E-02	1.334E-02	1.628E-02	1.895E-02	2.126E-02	2.312E-02	2.440E-02	2.488E-02
6.0000	C.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

DIMENSIONLESS MASS PICK-UP

SLCT LOCATION      MASS PICK-UP

0.24	1.10524E+00
0.19	1.10263E+00
0.14	1.09906E+00
0.10	1.09461E+00
0.05	1.08914E+00
0.00	1.08615E+00
-0.05	1.09025E+00
-0.10	1.09582E+00
-0.14	1.10026E+00
-0.19	1.10380E+00
-0.24	1.10638E+00

TEST CASE 5, HEPTANE SPILL (D.P.)

TC = 10.0 DEC C      CC = 113.55 GM/M\*\*3      P = 20.05 MM HG

HOLD VOID VOLUME = 2407.000 M\*\*3  
 AIR CHANGES/HOUR = 1.496 BASED ON TOTAL HOLD VOLUME

TOTAL MASS PICK-UP      2.62452E-02      GM/SEC

VAPOR CONCENTRATION IN EXHAUST AIR = 2.62452E-02      GM/M\*\*3

APPENDIX 3.

Computer Code Listing

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

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1  C SEALAND PROJECT, PROGRAM #10
2  C WRITTEN BY JOHN A. ROCKETT, JUNE 1979
3  C
4  C REF.: H.BAUM, THEORETICAL INVESTIGATION OF THE FLUID MOTIONS
5  C IN A CONTAINER SHIP HOLD. PRELIMINARY REPORT, JUNE, 1978.
6  C
7  C THIS VERSION IS BASED ON A FURTHER SIMPLIFICATION OF THE PROBLEM:
8  C THE TEMPERATURE FIELD STRONGLY STRATIFIES THE AIR
9  C THE STRATIFICATION IS STABLE.
10 C THE SIZE AND BULKHEAD VOIDS ARE THE SAME THICKNESS AND ESSENTIALLY
11 C FREE OF OBSTRUCTIONS TO VERTICAL AIR MOVEMENT. THIS ALLOWS
12 C A SINGLE SLOT TO APPROXIMATE THE INTERESTING FLOW IN THESE
13 C LARGE VOIDS.
14 C THIN INTER-CONTAINER VOIDS CONNECT TO THE ABOVE MAIN VOID AT
15 C WIDELY SPACED INTERVALS. THIS IS NOT STRICTLY TRUE SINCE
16 C THE MAIN VOID IS ABOUT 2 METERS THICK AND THE INTER-CONTAINER
17 C SLOTS MEET IT AT APPROXIMATELY 3 METER INTERVALS.
18 C
19 C THE MAIN PROGRAM MANAGES THE WHOLE CALCULATION
20 C
21 C DIMENSION XS(11),UB(10,11),UBO(11),W(10,11),WO(11)
22 C &,USLOT(31,11)
23 C &,ZPSI(31,31),XPSI(31),TOTAL(11)
24 C
25 C
26 C FORMAT(//,5X,'CONTAINER SHIP VENTILATION STUDY',/,10X,
27 C &'VERSION 10 - JUNE, 1979')
28 C
29 C FORMAT(//,10X,'SCALING PARAMETERS',/,12X,'GRASH =',
30 C + 1PE12.4,5X,'OMEGA =',1PE12.4,/,12X,'SQRT(F) =',1PE12.4)
31 C FORMAT(//,10X,'THE SCALE LENGTH FOR THE VOID, X= XL*FS, IS LESS TH
32 C &AN THE VOID WIDTH,, Y3.,/,15X,'X =',F7.2,, Y8 =',F7.2,/,
33 C & 10X,'THIS MODEL ASSUMES THE VOID IS NARROW COMPARED TO THE SCALE
34 C &LENGTH')
35 C FORMAT(//,12X,'GRSLOT =',1PE12.4,5X,'OMSLOT=',1PE12.4,
36 C + /,12X,'SQRT(FS)=' ,1PE12.4)
37 C FORMAT(//,10X,'THE SCALE LENGTH FOR THE SLOT, X= XSLOT*FSSLOT, IS
38 C &LESS THAN THE SLOT WIDTH, YSLOT.',/,15X,'X =',F7.2,, YSLOT =',
39 C & F7.2,/,10X,'THE MODEL REQUIRES THAT THE SLOT BE NARROW COMPARED T
40 C &O THE SCALE LENGTH.')
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52 00041CI 60 FORMAT(//,12X,'HOLD VOID VOLUME =',F10.3,' M**3',/
53      &      ,12X,'AIR CHANGES/HOUR =',F10.3,' BASED ON TOTAL HOLD VOLUME')
54 000478I 70 FORMAT(//,10X,'SUCTION MOVED TO AVOID SLOT-VOID INTERSECTION',/
55      +      10X,'XSINK =',1PE10.2,'TC XSINK =',1PE10.2)
56 000402I 75 FORMAT(4I5,1P4E15.6)
57 0004E0I 90 FORMAT(//,10X,'TOTAL MASS PICK-UP',15X,1PE15.5,2X,'GM/SEC')
58 00050EI 95 FORMAT(//,10X,'VAPOR CONCENTRATION IN EXHAUST AIR =',1PE13.5,
59      &      2X,'GM/M**3')
60
61 00054CI C CALL CARCON(6,1)
62 001E6CI C WRITE(6,10)
63
64 C AXIAL AND TRANSVERSE VELOCITIES FOR THE SLOT BOTTOM, IN
65 C OIMENSIONLESS FORM, ARE INDEPENDENT OF THE SLOT GEOMETRY
66 C AND OTHER EXTERNAL CONDITIONS AND CAN BE CALCULATED ONCE
67 C FOR ALL CASES.
68 C
69 001E88I C CALL INTEG1(U8,U80)
70 001EA4I C CALL INTEG2(U8,U80,W,W0)
71
72 C PRINT GEOMETRY INDEPENDENT RESULTS.
73 C
74 001EC8I C CALL PRINT(U3,U80,W,W0)
75
76 C THE PROGRAM IS SET UP TO COMPUTE MULTIPLE GEOMETRIC OR
77 C THERMAL CASES, LOOPING BACK TO LINE 100, BELOW, FOR
78 C EACH CASE.
79 C
80 C READ THE NUMBER OF CASES TO BE TREATED
81 C
82 001EECI READ(5,15) NGEOMS
83 001FOCI NGEOM=0
84 001F14I 100 CONTINUE
85 001F14I NGEOM=NGEOM + 1
86
87 001F22I C CALL INPUT(TK,DEL,XL,YB,H,D,XSLOT,YSLOT,NXSLOT,DSLOT,
88      &      NSLOTS,XS,XSINK,YSINK,VTOT,VVOID,NCHEMS,SPACE)
89
90 C CALCULATION OF BASIC PARAMETERS OF THE MAIN AND SLOT FLOWS
91 C
92 C FIND SCALING PARAMETERS
93 C
94 C FOR AIR ASSUME
95 C DENSITY 0.001205 GM/CM**3
96 C VISCOSITY 180.8 MICROPOISE
97 C PR 0.74
98 C
99 001F7CI PR=0.74
100 001F88I VISC=0.01808
101 001F94I VISKIN=0.15004E-4
102 001FA0I GRAV=9.80665

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103 C
104 C
105 C
106 C
107 C
108 C
109 C
110 C
111 C
112 C
113 C
114 C
115 C
116 C
117 C
118 C
119 C
120 C
121 C
122 C
123 C
124 C
125 C
126 C
127 C
128 C
129 C
130 C
131 C
132 C
133 C
134 C
135 C
136 C
137 C
138 C
139 C
140 C
141 C
142 C
143 C
144 C
145 C
146 C
147 C
148 C
149 C
150 C
151 C
152 C
153 C

MAIN VOID PARAMETERS
D3=D**3
GRASH= GRAV*DELT*D3/(TK*VISKIN*VISKIN)
OMEGA=((GRASH*PR*D/H)**0.25)/SQRT(2.)
F=(3./8.*(OMEGA**3))*((SINH(2.*OMEGA))-SIN(2.*OMEGA))/
& ((COSH(OMEGA))**2-(SIN(OMEGA))**2))
FS=SQRT(F)
WRITE(6,20) GRASH,OMEGA,FS
INTERCONTAINER SLOTS
DSL3=DSL3**3
GRSLOT= GRAV*DELT*DSL3/(TK*VISKIN*VISKIN)
OMSLOT= ((GRSLOT*PR*DSL3/H)**0.25)/SQRT(2.)
FSL3= (3./8.*(OMSLOT**3))*((SINH(2.*OMSLOT))-SIN(2.*OMSLOT))/
& ((COSH(OMSLOT))**2-(SIN(OMSLOT))**2))
FSSLOT=SQRT(FSL3)
WRITE(6,40) GRSLOT,OMSLOT,FSSLOT

THE MODEL ASSUMES THAT THERE ARE NO PRESSURE GRADIENTS
ACROSS THE NARROW DIMENSION OF THE VOID.
THIS IS VALID PROVIDED THE SCALE LENGTH, X=XL*FS, IS LARGE
COMPARED TO THE VOID WIDTH.
CHECK TO SEE THAT THIS RESTRICTION IS MET BY THE INPUT DATA.

X=XL*FS
IF(X.GT.YB) GO TO 150
WRITE(6,30) X,YB
STOP

CHECK TO SEE THAT SLOT WIDTH IS LESS THAN SLOT SCALE LENGTH.

CONTINUE
X=XSL3*FSSLOT
IF(X.GT.YSLOT) GO TO 200
WRITE(6,50) X,YSL3
STOP

CONTINUE
200 CONTINUE

THE SLOTS SHOULD BE WIDELY SPACED COMPARED TO THE VOID WIDTH.
THIS MAY WELL NOT BE TRUE FOR SOME SHIPS. WE NOTE THE
SCALED RATIO, BUT TAKE NO ACTION IF IT ISN'T LARGE.

TEST=SPACE*FS
RATIO = TEST/YB
WRITE(6,52) SPACE,YB,RATIO
IF(RATIO.LT.0.5) GO TO 250
WRITE(6,54)

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154 C 250 CONTINUE
155 C
156 C
157 C WE WANT TO AVOID HAVING THE MAIN SUCTION (SINK) LIE ON A SLOT-VOID
158 C INTERSECTION. IF IT DOES, MOVE IT HORIZONTALLY A DISTANCE LESS THAN
159 C THE SPATIAL RESOLUTION OF THE CALCULATION
160 C
161 C
162 C
163 C
164 C
165 C
166 C
167 C
168 C
169 C
170 C
171 C
172 C
173 C
174 C
175 C
176 C
177 C
178 C
179 C
180 C
181 C
182 C
183 C
184 C
185 C
186 C
187 C
188 C
189 C
190 C
191 C
192 C
193 C
194 C
195 C
196 C
197 C
198 C
199 C
200 C
201 C
202 C
203 C
204 C

00244CI
00245CI
00246CI
00247CI
00248CI
00249CI
00250CI
00251CI
00252CI
00253CI
00254CI
00255CI
00256CI
00257CI
00258CI
00259CI
00260CI
00261CI
00262CI
00263CI
00264CI
00265CI
00266CI
00267CI
00268CI
00269CI
00270CI
00271CI
00272CI
00273CI
00274CI
00275CI
00276CI
00277CI
00278CI
00279CI
00280CI
00281CI
00282CI
00283CI
00284CI
00285CI
00286CI
00287CI
00288CI
00289CI
00290CI
00291CI
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SAVE = XSINK
NFLAG = 0
DO 400 J = 1, NSLOTS
TEST1 = XS(J) + 0.05
TEST2 = XS(J) - 0.05
IF ((XSINK.LT.TEST1).AND.(XSINK.GE.XS(J))) GOTO 300
IF ((XSINK.GT.TEST2).AND.(XSINK.LE.XS(J))) GOTO 350
CONTINUE
XSINK = XSINK + 0.005*XL
NFLAG = 1
GOTO 401
XSINK = XSINK - 0.005*XL
NFLAG = 1
CONTINUE
IF (NFLAG.GT.0) WRITE(6,70) SAVE,XSINK

CHECK TO SEE IF THE SUCTION IS TOO CLOSE TO THE TANK TOP.
THE MODEL ASSUMES IT IS IN THE INTERIOR OF THE SPACE,
NOT ON THE BOUNDARY. IF IT IS LOW, MOVE IT UP TO 5 CM.

IF (XSINK.GE.0.05) GO TO 500

WRITE(6,58) XSINK
XSINK = 0.05

WRITE(6,56) XSINK,XSINK

NOTE: QVOID AND QSLOT ARE BASED ON UNIT TOTAL FLOW. SINCE THEY
ARE USED ONLY AS THE RATIO QSLOT/QVOID THIS IS OK.
IT IS ASSUMED THAT NO MASS PICK-UP OCCURS IN THE
MAIN VOID.

QSUM = D3*XL*F + NSLOTS*(DSL3*XSLOT*FSLT)
QVOID= (D3*XL*F/QSUM)
QSLOT= (DSL3*XSLOT*FSLT/QSUM)

WE WILL WANT TO PLOT STREAMLINES FOR THE FLOW ALONG THE SLOT
BOTTOM AND THE PRESSURE AT THE OPEN END OF THE SLOT (SLOT-
VOID INTERSECTION). HOWEVER, ONLY THE VALUES FOR THE SLOTS
CLOSEST TO AND FURTHEST FROM THE SUCTION ARE OF INTEREST
SINCE THESE QUANTITIES DON'T VARY A GREAT DEAL.

IDENTIFY THE SLOT INICIES, NMIN AND NMAX, FOR THE SLOTS CLOSEST
TO AND FURTHEST FROM THE SUCTION.

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

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205      C
206      002672I      NMIN=0
207      00267AI      NMAX=0
208      002682I      REF1=0.
209      00268EI      REF2=XL
210      C
211      00269AI      DO 550 J=1,NSLOTS
212      0026AEI      TEST=ABS(XS(J)-XSINK)
213      0026E2I      IF(TEST.GT.REF1) NMAX=J
214      002700I      IF(TEST.GT.REF1) REF1=TEST
215      00271EI      IF(TEST.LT.REF2) NMIN=J
216      00273CI      IF(TEST.LT.REF2) REF2=TEST
217      00275AI      CONTINUE
218      550
219      C
220      PUT HEADER INFORMATION ON STREAMLINE PLOT FILE
221      C
222      WRITE(7,75) NXSLT,NSLOTS,NMIN,NMAX,XS(NMIN),XS(NMAX),XSINK,YSINK
223      C
224      PUT SLOT LOCATIONS, XS AND SUCTION LOCATION, XSINK, YSINK
225      C
226      IN DIMENSIONLESS FORM IN VOID COORDINATE SYSTEM.
227      C
228      DO 600 N=1,NSLOTS
229      0027D4I      XS(N)=XS(N)/XL
230      0027E8I      CONTINUE
231      600
232      XSD=XSINK/XL
233      YSD=YSINK/(XL*FS)
234      C
235      SLOT FLOW IS BASED ON A PRESSURE DERIVED FROM THE MAIN VOID.
236      C
237      SLOT VARIABLES MUST BE CALCULATED FOR EACH SLOT
238      C
239      SINCE EACH SLOT SEES A DIFFERENT END PRESSURE.
240      C
241      THE CALCULATION PROCEEDS AS FOLLOWS:
242      C
243      FOR EACH SLOT IN TURN -
244      C
245      1.) CALL SLOT1 - THIS SETS UP VALUES TO
246      C
247      CALCULATE PARTIAL P/PARTIAL X FOR Y=0. THIS IS THE
248      C
249      AXIAL VELOCITY NEAR THE BOTTOM OF THE SLOT USLOT(X).
250      C
251      USLOT IS CALCULATED BY CALLS FROM SLOT1 TO THE EXTERNAL
252      C
253      FUNCTIONS GRAD (S10GRAD.FTN) AND PRESS (S10PRESS.FTN)
254      C
255      AND IS TABULATED, FOR EACH SLOT, N, FOR NXSLT LOCATIONS,
256      C
257      XCI), GIVING A MATRIX USLOT(I,N).
258      C
259      2.) CALL STRM1 - THIS GENERATES STREAMLINES FOR THE FLOW
260      C
261      ALONG THE SLOT BOTTOM USING W0 (FROM INTEG2) AND USLOT(I,N).
262      C
263      3.) CALL PICKUP1 - THIS INTEGRATES THE LOCAL MASS PICK-UP
264      C
265      ALONG THE STREAMLINES FROM WHERE THEY LEAVE THE SIDE
266      C
267      WALL OF THE SLOT TO WHERE THEY ENTER THE MAIN VOID.
268      C
269      THE MASS PICK-UP OF THE INDIVIDUAL STREAM TUBES IS
270      C
271      THEN INTEGRATED ACROSS THE END OF THE SLOT TO GIVE THE
272      C
273      TOTAL PICK-UP FOR THAT SLOT.
274      C
275      4.) THE CALCULATION THEN LOOPS BACK REPEATING THE ABOVE
276      C
277      FOR EACH SLOT AND ADDING THE INDIVIDUAL SLOT MASS
278      C
279      PICK-UPS TO GIVE THE TOTAL.
280      C

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

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256 C
257 00284AI PICKUP = 0.
258 C
259 002856I DO 700 N=1,NSLOTS
260 00286AI CALL SLOT1(NXSLOT,USLOT,N,XS,D3,DSL3,XL,XSLOT,FS
261 8 ,FSSLT,XSD,YSD,QVOIC,QSLOT,NSLOTS)
262 C
263 002888I CALL STRM1(NXSLT,USLOT,W0,ZPSI,N,IMAX,XPSI,NMIN,NMAX)
264 C
265 0028F0I CALL PICUP1(NXSLT,ZPSI,XPSI,USLOT,W0,UB0,TOTAL,N,IMAX)
266 C
267 002928I PICKUP = PICKUP + TOTAL(N)
268 002940I CONTINUE
269 C
270 C
271 C PRINT SLOT RESULTS.
272 C
273 002958I CALL PRINT1(XSLOT,NXSLT,USLOT,XS,NSLOTS,XL,
274 8 W0,TOTAL)
275 C
276 C COMPUTE DIMENSIONAL PICK-UP FOR SPECIFIC CHEMICALS AND
277 C VENTELATION RATES
278 C
279 C GET DATA ON CHEMICAL
280 C
281 NCHEM = 0
282 CONTINUE
283 800 CALL INPUT1(DIFFU,CO,TK,NFLOWS)
284 C
285 C GET VENTELATION RATES TO BE USED WITH THIS CHEMICAL
286 C
287 NFLOW=0
288 CONTINUE
289 900 CALL INPUT2(Q0)
290 C
291 C MASS PICK-UP
292 C
293 GAM13=2.67894
294 SC=VISKIN/DSLST
295 RE=(3.*Q0*QSLOT*DSLST)/(2.*FSSLT*VISKIN*(XSLOT**2))
296 E=1./3.
297 COMASS=(3.*DIFFU*XSLOT)*CO*((3.*RE*SC)**E)/GAM13
298 C
299 C FIND HOLD VOID VOLUME AND AIR CHANGES PER HOUR
300 C
301 VOL=VTOT
302 AIRCH=(3600.*Q0)/VOL
303 WRITE(6,60) VOL,AIRCH
304 C
305 C RECALL THAT NO MASS PICK-UP OCCURS IN THE MAIN VOID!
306 C
307 SWEEP = COMASS*PICKUP

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307 002AEEI      WRITE(6,90) SWEEP
308 002B0CI      CONC=SWEEP/QO
309 002B1EI      WRITE(6,95) CONC
310 002B3CI      NFLOW=NFLOW + 1
311 002B4AI      IF (NFLOW.LT.NFLOWS) GOTO 900
312 C
313 002B6OI      NCHEM=NCHEM + 1
314 002B6EI      IF (NCHEM.LT.NCHEMS) GOTO 800
315 C
316 C      WE WANT TO PLOT SLOT END PRESSURES FOR SLOTS N=MIN AND N=NMAX.
317 C      THIS WILL BE DONE BY A SEPARATE PROGRAM USING PRESSURE VALUES
318 C      STORED IN A DISK FILE.
319 C      THE CALL TO PPLOT IS TO BUILD THIS DISK FILE.
320 C
321 002B84I      CALL PPLOT(XS,NMIN,NMAX,J3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,YSD,
322 C      & QVOID,QSLOT,NSLOTS,NXSLOT)
323 C
324 C      LOOP BACK TO PICK UP ADDITIONAL CASES AS NEEDED
325 C
326 002B84I      IF(NGEOMS.GT.NGEOM) GO TO 100
327 C
328 002B8AI      STOP
329 002B8F2I      END

```

NO ERRORS:F7D R04-00 MAINPROG .MAIN 06/24/81 08:12:44 TABLE SPACE: 7 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 166 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, G4-101M99.

```

1 00000001      SUBROUTINE INTEG1(UB3,UB0)
2
3      C
4      C THIS ROUTINE CARRIES OUT INTEGRALS NEEDED TO DEFINE THE VELOCITY
5      C IN THE BOTTOM OF A SLOT (OR THE MAIN VOID)
6      C THE VELOCITY CALCULATED IS FOR THE VOLUME FROM THE BOTTOM OF
7      C THE SLOT TO APPROXIMATELY ONE SLOT WIDTH UP. THE ASSUMPTION IS
8      C MADE THAT THE VELOCITY GOES ASYMPTOTICALLY TO THAT FOUND FOR THE
9      C MAIN PART OF THE SLOT.
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41      C
42      C
43      C
44      C
45      C
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50      C
51      C

```

THIS ROUTINE CARRIES OUT INTEGRALS NEEDED TO DEFINE THE VELOCITY  
 IN THE BOTTOM OF A SLOT (OR THE MAIN VOID)  
 THE VELOCITY CALCULATED IS FOR THE VOLUME FROM THE BOTTOM OF  
 THE SLOT TO APPROXIMATELY ONE SLOT WIDTH UP. THE ASSUMPTION IS  
 MADE THAT THE VELOCITY GOES ASYMPTOTICALLY TO THAT FOUND FOR THE  
 MAIN PART OF THE SLOT.

$UB(J,K) = UB(Y,Z)$  IS THE AXIAL VELOCITY NEAR THE SLOT BOTTOM  
 $UB0(K) = 20 * UB(Z,Y=0.05)$  APPROXIMATES  $UB'$  = PARTIAL  $UB$  PARTIAL  $Y$   
 AT  $Y=0$

$X$  = COORDINATE ALONG SLOT LENGTH, DOES NOT FIGURE IN THIS CALCULATION  
 $Y$  = DIMENSIONLESS COORDINATE UP FROM SLOT BOTTOM  
 $Z$  = " " ACROSS SLOT WIDTH

THE QUANTITY FORMED IS

$UB(Y,Z) = (1-Z**2) - \text{INTEGRAL } (-1 \text{ TO } 1) \text{ OF } Z0 * J(Y,Z,Z0) \text{ D}Z0$   
 FOR  $J$  SEE H. BAUM NOTES

DIMENSION  $UB(10,11), UB0(11)$

10 POINTS IN  $Y$  (UP) AND 10 IN  $Z$  (ACROSS) ARE TABULATED  
 $Y$  VARIES 0 TO 1 IN STEPS OF 0.1  
 $Z$  " 0 " 1 " " 0.1,  $Z=0$ . ON CENTER LINE  
 20 POINTS ARE USED IN THE INTEGRAL,  $Z0$  -1. TO 1.

$N=10$   
 $N1=N+1$   
 $DEL=1./(FLOAT(N))$   
 $N0=20$   
 $DELO=2./(FLOAT(N0))$   
 $PI=3.141592654$   
 $PIHALF=1.570796327$   
 $TOL0=C.0001$   
 $Y=DEL$

BEGIN INTEGRATION. TRAPEZOIDAL RULE USED

DO 800  $J=1,N1$   
 $Z=0$ .

DO 700  $K=1,N1$   
 $SUM=0$ .  
 $Z0=-1$ .  
 $R=\sin(PIHALF * Z) * \cosh(PIHALF * Y)$   
 $A=\cos(PIHALF * Z) * \sinh(PIHALF * Y)$

THE TESTS WHICH FOLLOW ARE TO GET THE ARCTAN IN THE CORRECT SECTOR

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

52      C
53      0001C4I
54      TEST=R-RO
55      IF(TEST.LT.TOLO) GOTO 20C
56      TERM=ZC*(1./PI)*ATAN(A/(R-RO))
57      GOTO 300
58      CONTINUE
59      200
60      IF(TEST.GT.-TOL0) GOTO 250
61      TERM=ZC*(1.- (1./PI)*ATAN(A/(R-RO)))
62      GOTO 300
63      CONTINUE
64      250
65      TERM=0.5*Z0
66      CONTINUE
67      300
68      MAIN INTEGRATION LOOP
69      C
70      DO 600 I=1,N0
71      Z0=Z0+DELO
72      RO=SIN(PI*HALF*Z0)
73      TEST=R-RO
74      IF(TEST.LT.TOLC) GOTO 400
75      TERM1=ZC*(1./PI)*ATAN(A/(R-RO))
76      GOTO 500
77      CONTINUE
78      400
79      IF(TEST.GT.-TOL0) GOTO 450
80      TERM1=Z0*(1.- (1./PI)*ATAN(A/(R-RO)))
81      GOTO 500
82      CONTINUE
83      450
84      TERM1=0.5*Z0
85      CONTINUE
86      500
87      SUM=SUM+TERM+TERM1
88      TERM=TERM1
89      CONTINUE
90      600
91      SUM=SUM*DELO*C.5
92      SUM=0.5*(1.-Z**2)-SUM
93      IF(J.EQ.N1) GOTO 650
94      UB(J,K)=SUM
95      Z=Z+DEL
96      GOTO 700
97      CONTINUE
98      650
99      UB0(K)=SUM*20.
100      Z=Z+DEL
101      CONTINUE
102      700
103      Y=Y+DEL
104      IF(J.EQ.N) Y=0.05
105      CONTINUE
106      800
107      RETURN
108      END

```

FORTAN-VIID R04-00

FORTAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

NO ERRORS:F7D R04-00 SUBROUTINE INTEG1 06/24/81 08:13:46 TABLE SPACE: 3 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 201 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 000000I
2 C
3 C
4 C
5 C
6 C
7 C
8 C
9 C
10 C
11 000004I
12 C
13 000004I
14 000024I
15 000032I
16 C
17 000056I
18 000064I
19 C
20 000084I
21 000098I
22 0000A6I
23 000134I
24 C
25 00014CI
26 C
27 000164I
28 C
29 000174I
30 000188I
31 000196I
32 0001F4I
33 C
34 00020CI
35 000212I

SUBROUTINE INTEG2(UB,UB0,W,W0)
THIS ROUTINE FORMS W, THE INDEFINATE INTEGRAL ON UB W.R.T. Z
TRAPOZOIDAL RULE IS USED
W0 IS THE ANALOGOUS INTEGRAL OF UB0
W0 IS USED TO FORM THE STREAM FUNCTION AT THE BOTTOM
OF A SLOT.
DIMENSION UB(10,11),W(10,11),UB0(11),W0(11)
N=10
N1=N+1
DEL=1./(FLOAT(N))
DO 200 J=1,N
W(J,1)=0.
DO 100 K=2,N1
K1=K-1
W(J,K)=W(J,K1)+0.5*DEL*(UB(J,K)+UB(J,K1))
CONTINUE
100 CONTINUE
200 CONTINUE
W0(1) = 0.
DO 300 K=2,N1
K1=K-1
W0(K)=W0(K1)+0.5*DEL*(UB0(K)+UB0(K1))
CONTINUE
300 CONTINUE
RETURN
END

```

NO ERRORS:F7D R04-00 SUBROUTINE INTEG2 06/24/81 08:14:39 TABLE SPACE: 2 KB  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 189 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIIO: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE INPUT(TK,DELT,XL,Y5,H,D,XSLOT,YSLOT,NXSLOT,DSLOT,
2 + NSLOTS,XS,XSINK,YSINK,VTOT,VVOID,NCHEMS,SPACE)
3
4 C
5 C
6 C
7 C
8 C
9 C
10 C
11 C
12 C
13 C
14 C
15 C
16 C
17 C
18 C
19 C
20 C
21 C
22 C
23 C
24 C
25 10
26 20
27 30
28 40
29
30
31
32
33
34 0001061 &X,DELT='F9.6,10X,DEG C',/12X,XL='F5.2,5X,Y8='F5.2,
35 &F5.2,5X,ZH='F5.2,M',/12X,XSLOT='F5.2,5X,YSLOT='F5.2,
36 &14X,M',/10X,I3,' INTERCONTAINER SLOTS SPACED='F5.2,M',
37 &/10X,'NUMBER OF POINTS TABULATED:',
38 &/12X,NXSLOT='I3)
39 &F5.2,10X,'IS GREATER THAN THE INPUT VOID LENGTH,'F5.2)
40 C
41 0001FEI IFLAG=0
42 00020C1 READ(5,10) DELT
43
44 C
45 C
46 C
47 C
48 C
49 C
50 C
51 00022C1 TC = 10.0
52 0002381 TOK=273.16
53 0002441 TK=TC+TOK
54 0002561 READ(5,20) XL,Y8,H

```

INPUT DATA IN ORDER OF ENTRY WITH APPROPRIATE UNITS

DELT = TEMPERATURE RISE FROM BOTTOM TO TOP OF VERTICLE SLOTS, DEG C

XL = LENGTH OF MAIN VOID, M

Y5 = WIDTH OF MAIN VOID, M

H = HEIGHT OF MAIN VOID AND INTERCONTAINER SLOTS, M

XSLOT = LENGTH OF INTERCONTAINER SLOTS, M

YSLOT = WIDTH OF INTERCONTAINER SLOTS, M

SPACE = DISTANCE BETWEEN INTERCONTAINER SLOTS (CONTAINER WIDTH), M

NXSLOT= NUMBER OF X POINTS FOR TABULATION OF SLOT VARIABLES

NSLOTS= NUMBER OF INTERCONTAINER SLOTS (NUMBER OF CONTAINERS + OR - 1)

XS = X LOCATION OF SLOT INTERSECTION WITH MAIN VOID

XSINK = X LOCATION OF MAIN VOID SOURCE (SINK), M

YSINK = Y " " " "

VTOT = TOTAL VOLUME OF THE EMPTY HOLD

VVOID = HOLD VOLUME - TOTAL VOLUME OF CONTAINERS LOADED

NCHEMS= NUMBER OF SETS OF CHEMICAL DATA TO BE ENTERED

DATA TO BE REAC.

DIMENSION XS(11)

FORMAT (2F10.2)

FORMAT (5F10.2)

FORMAT (3I10)

FORMAT(1H1,/,10X,'INPUT PARAMETERS:',/12X,TC='F5.2,

&X,DELT='F9.6,10X,DEG C',/12X,XL='F5.2,5X,Y8='F5.2,

&F5.2,5X,ZH='F5.2,M',/12X,XSLOT='F5.2,5X,YSLOT='F5.2,

&14X,M',/10X,I3,' INTERCONTAINER SLOTS SPACED='F5.2,M',

&/10X,'NUMBER OF POINTS TABULATED:',

&/12X,NXSLOT='I3)

FORMAT(10X,'\*\*\*\*\*',5X,'\*\*\*\*\*',5X,'\*\*\*\*\*',

&5X,'\*\*\*\*\*',/)

FORMAT(10X,'NSLOTS TOO LARGE, MAX 30! INPUT NSLOTS ='I4)

FORMAT(10X,'NXSLOT TOO LARGE, MAX 11! INPUT NXSLOT ='I4)

FORMAT(10X,'VOID LENGTH IMPLIED BY INTERCONTAINER SPACING,'

&F5.2,10X,'IS GREATER THAN THE INPUT VOID LENGTH,'F5.2)

IFLAG=0

READ(5,10) DELT

TC, THE AMBIENT TEMPERATURE IS NOT INPUT HERE BUT SET AT A

NOMINAL VALUE. IT WILL BE READ LATER, IN INPUT1, FOR

SPECIFIC CALCULATIONS FOR VARIOUS CHEMICALS.

TC = 10.0

TOK=273.16

TK=TC+TOK

READ(5,20) XL,Y8,H

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```

52 00027CI      D=YB*0.5
53 00028EI      READ(5,20) XSLOT,YSLOT,SPACE
54 00029AI      DSLOT=YSLOT*0.5
55 0002C6I      READ(5,30) NXSLLOT,NSLOTS
56 0002E8I      IF (NSLOTS.GT.11) IFLAG=1
57 000300I      IF (NXSLLOT.GT.30) IFLAG=3
58 000318I      IF (IFLAG.GT.0) GOTO 400
59
60 00032EI      C
61 000370I      WRITE(6,40) TC,DELT,XL,YB,H,XSLLOT,YSLOT,NSLOTS,SPACE,NXSLLOT
62 000390I      N=(NSLOTS/2)*2
63 0003A8I      IF(N.EQ.NSLOTS) GOTO 200
64 0003C2I      N=NSLOTS/2
65 0003E4I      X=SPACE*(FLOAT(N))
66
67 0003F8I      C
68 000412I      DO 150 I=1,NSLOTS
69 000424I      XS(I)=X
70 00043CI      X=X-SPACE
71 00043CI      CONTINUE
72 000442I      GOTO 300
73 000442I      C
74 000442I      200 CONTINUE
75 00045EI      N=(NSLOTS/2)-1
76 00048EI      X=(SPACE/2.)*SPACE*(FLOAT(N))
77 0004A2I      DO 250 I=1,NSLOTS
78 00048EI      XS(I)=X
79 00048CI      X=X-SPACE
80 0004CEI      CONTINUE
81 0004E6I      250 CONTINUE
82 0004E6I      C
83 0004E6I      300 CONTINUE
84 00050AI      XSTEST=XS(1)-XS(NSLOTS)
85 000522I      IF (XSTEST.GT.XL) GOTO 500
86 000544I      READ(5,20) XSINK,YSINK
87 000544I      C
88 000544I      READ(5,20) VTOT,VVOID
89 000568I      C
90 000568I      READ(5,30) NCHEMS
91 000588I      C
92 000588I      RETURN
93
94 00058EI      C
95 00058EI      400 CONTINUE
96 0005A8I      WRITE(6,80)
97 0005D8I      IF (IFLAG.EQ.1) WRITE(6,81) NSLOTS
98 000608I      IF (IFLAG.EQ.3) WRITE(6,83) NXSLLOT
99 000610I      STOP
100 000610I      C
101 000634I      500 WRITE(6,90) XSTEST,XL
102 000634I      STOP

```

06/24/81 08:15:42 PAGE 3/

FORTRAN-VIID R04-00

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

103  
104103  
104 00063CI ENDNO ERRORS:F7D R04-00 SUBROUTINE INPUT 06/24/81 08:16:14 TABLE SPACE: 3 KB  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 126 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN-VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE SLOT1(NXSLOT,USLOT,N,XS,D3,DSL3,XL,XSLOT,FS
2      & ,FSSLOT,XSD,YSD,QVOID,QSLOT,NSLOTS)
3      C
4      C THIS IS FOR A SLOT OPEN AT ONE END ONLY
5      C
6      C IT CALCULATES USLOT(I,N) = PARTIAL P/PARTIAL X FOR Y=0 AT
7      C X = X(I) FOR THE SLOT INTERSECTING THE MAIN VOID AT XS(N).
8      C
9      C FOR EQUATIONS SEE H.BAUM NOTES: SECONDARY PASSAGE FORMULAE
10     C NOTATION FOLLOWS BAUM
11     C IN THE STATEMENT FUNCTION GRAD THE LAST VARIABLE IN THE LIST,
12     C K, WHEN SET = 1, INTEGRATES PRESSURES WITH A FIXED INTERVAL
13     C SIZE. WHEN K = 0 THE INTEGRATION IS REPEATED WITH VARIOUS
14     C INTERVALS UNTIL A PRESET ACCURACY IS ACHIEVED.
15     C
16     C DIMENSION XS(11),USLOT(31,11)
17     C
18     C K=1
19     C NX1=NXSLOT+1
20     C DELX=1./NXSLOT
21     C
22     C DO 100 I = 1,NX1
23     C X = -0.5 + DELX*(I-1)
24     C USLOT(I,N)=GRAD(X,XS,N,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,YSD,
25     C QVOID,QSLOT,NSLOTS,K)
26     C
27     C 100 CONTINUE
28     C
29     C RETURN
30     C END

```

NO ERRORS:F7D R04-00 SUBROUTINE SLOT1 06/24/81 08:17:14 TABLE SPACE: 2 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 108 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 000000I      FUNCTION GRAD(X,XS,N,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,YSD,
2      & QVOID,QSLOT,NSLOTS,K)
3
4      C
5      C
6      C
7      C
8      C
9      C
10     C
11     C
12     C
13     C
14     C
15     C
16     C
17     C
18     000018I      DIMENSION XS(11)
19
20     C
21     C
22     C
23     C
24     C
25     C
26     C
27     C
28     C
29     C
30     C
31     C
32     C
33     C
34     C
35     C
36     C
37     C
38     C
39     C
40     C
41     C
42     C
43     C
44     C
45     C
46     C
47     C
48     C
49     C
50     C
51     C

```

WRITTEN BY: D. CORLEY, JUNE 1979  
 REVISED, SEPTEMBER, 1979

CALC DP/DX=G(X)+INTEG 0 TO INF DP/DY\*F(X,Y)\*DY  
 X = LOCATION ALONG THE SLOT, DIMENSIONLESS IN SLOT COORDINATES  
 XS= LOCATION ALONG THE VOID, " " VOID  
 D3,DSL3 ARE HALF-WIDTHS OF VOID, SLOT CUBED  
 XL,XSLOT ARE LENGTHS OF VOID, SLOT IN PHYSICAL COORDINATES  
 FS,FSSLOT ARE SQR(F(OMEGA)) FOR VOID, SLOT  
 XSD,YSD ARE LOC OF SOURCE, DIMENSIONLESS IN VOID COORDINATES  
 QVOID,QSLOT ARE SOURCE STRENGTH IN VOID, SLOT  
 NSLOTS IS NUMBER OF SLOTS(GREATER THAN ONE)  
 N IS THE NUMBER OF THE SLOT WHERE THE VELOCITY IS DESIRED.

THE FOLLOWING ARE FUNCTION DEFINITIONS

```

      G(X)=COS(PI*X)/SQRT(1.+SIN(PI*X))
      F(X,Y)=SQRT(COSH(PI*Y)-1.)/(SIN(PI*X)+COSH(PI*Y))
      YB(Y)=FSSLOT*XSLT*Y/(FS*XL)
      PL(Y)=QVOID*DSL3*FSSLOT*PRESS(XS,N,YB(Y),XSD,YSDS,
      & QVOID,QSLOT,NSLOTS)/(QSLOT*D3*FS)
      PI=4.*ATAN(1.)

```

IF XS(N) = XSD THE COMPUTATION WILL DIVERGE. THIS IS SUPPOSED  
 TO HAVE BEEN AVOIDED BY A CHECK ON XS(N) AND XSD IN THE MAIN  
 PROGRAM.

```

      IF(XS(N).EQ.XSD)GO TO 700

```

NOTE: THE AXIAL VELOCITY EXPRESSION HAS TROUBLE AT X = -0.5, SO  
 WE EVALUATE THE VELOCITY NEAR, BUT NOT AT THE MOUTH OF THE  
 SLOT.

```

      IF(X.LE.-.5)X=-.498
      YSDS=YB(YSD)

```

IF K = 1 DO THE INTEGRAL ONCE WITH FIXED STEP SIZE

```

      IF(K.EQ.0) GO TO 400
      H2=0.
      H = 0.02
      TOL=0.0001
      SUM=0.
      A1=PL(H2)
      B1=F(X,H2)
      A4=0.

```

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

52 0004A4I      200 H2=H2 + H
53 0004B6I      YD=YSDS
54 0004C2I      IF(H2.EQ.YSDS) YD=YSDS+C.001
55 0004E6I      A2=PL(H2)
56 000500I      B2=F(X,H2)
57 000520I      A3=A2-A1
58 000532I      B3=B2+B1
59 000544I      SUM=SUM + 0.5*A3*B3
60
61 C
62 C SUM UNTIL PL(2) - PL(1) LESS THAN TOLERANCE (TOL) AND
63 C Y GREATER THAN 3.
64
65 IF(A3-A4.LT.TOL.AND.H2.GE.3) GO TO 300
66 A1=A2
67 B1=B2
68 A4=A3
69 GO TO 200
70 GRAD=SUM*G(X)
71
72 C
73 C INTEGRAL FROM H2 TO INFINITY OF EXP(-PI*Y/2.)
74
75 H=2.*EXP(-H2*PI/2.)/PI
76 GRAD = GRAD + H
77 RETURN
78
79 C IF K = 0 ITERATE INTEGRAL UP TO 4 TIMES, EACH TIME
80 C CUTTING STEP SIZE IN HALF.
81
82 C
83 C
84 C
85 C
86 C
87 C
88 C
89 C
90 C
91 C
92 C
93 C
94 C
95 C
96 C
97 C
98 C
99 C
100 C
101 C
102 C

```

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

103 0007AAI      IF(YTEST.LT.-3.0) A2=C.
104 0007C8I      IF(YTEST.GE.-3.0.AND.YTEST.LE.3.0) A2=PL(HI)
105 000808I      IF(YTEST.GT.3.0) A2=YB(HI)
106 000834I      B2=F(X,HI)
107 000854I      A3=A2-A1
108 000866I      33=B1+B2
109 000878I      SUM=SUM+.5*A3*B3
110 000896I      A1=A2
111 0008A2I      B1=B2
112 0008AEI      100 CONTINUE
113 0008C6I      IF(ABS((SUM-TEST)/SUM).LE.TOL)GO TO 301
114 000906I      IF(ICT.LT.4)GO TO 201
115 00091AI      WRITE(6,1)ICT,H,TEST,SUM
116 000944I      1 FORMAT(1H,'ERROR IN GRAD',I5,3(1PE12.4))
117 00096AI      301 GRAD=SUM*G(X)
118 000988I      SU=SU+SUM
119 00099AI      IF(IFL.EQ.1)GO TO 500
120 0009B0I      H1=1
121 0009BCI      H2=3
122 0009C8I      H=.1
123 0009D4I      IFL=1
124 0009DCI      GO TO 401
125 0009EOI      500 CONTINUE
126 0009EOI      GRAD=SU+.0057
127
128 C
129 C
130 C      .0057 IS THE INTEGRAL FROM 3 TO INF OF EXP(-PI*Y/2).
131 RETURN
132 700 WRITE(6,7) N, XS(N)
133 7 FORMAT(1H1,' ERROR, FOR N =',I4,' XS(N) = XSD =',1PE10.2)
134 000A6EI      RETURN
135 000A6EI      END

```

NO ERRORS:F7D R04-00 FUNCTION GRAD 06/24/81 08:18:53 TABLE SPACE: 4 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 122 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN VIIO: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001      C      FUNCTION PRESS(ZXS,N,ZY,ZXSD,ZYSDS,ZQVOID,ZQSLOT,NSLOTS)
2                                C
3                                C      WRITTEN BY D. CORLEY, MAY 1979
4                                C
5                                C      NOTATION FOLLOWS H. BAUM
6                                C
7 0000181      C      IMPLICIT DOUBLE PRECISION (A-H,O,Q-Y)
8 0000181      C      DOUBLE PRECISION PI,XP,XXM
9 0000181      C      DIMENSION A(4),B(4),XS(11),ZXS(11)
10
11     C      NSLOTS SLOTS AND 1 MAIN VOID, (NSLOTS+1) IN ALL
12     C      X,Y ARE DIMENSIONLESS POSITION OF POINT WHERE PRESSURE IS NEEDED
13     C      XSD,YSDS ARE DIMENSIONLESS POSITION OF SOURCE
14     C      QSLOT ARE VOL FLUX INTO INTERCONTAINER SLOTS
15     C      QVOID IS VOL FLUX INTO MAIN VOID
16     C      X GOES FROM -.5 TO +.5
17     C      Y GOES FROM 0 TO (INFINITY)
18     C      THE SLOTS ARE LOCATED AT POSITIONS XS
19     C      WE ARE INTERESTED IN THE SLOT AT XS(N).
20
21     Y      =DBLE(ZY)
22     XSD  =DBLE(ZXSD)
23     YSDS =DBLE(ZYSDS)
24     QVOID=DBLE(ZQVOID)
25     QSLOT=DBLE(ZQSLOT)
26     DO 20 I=1,11
27     XS(I)=DBLE(ZXS(I))
28     CONTINUE
29
30     C
31     X=XS(N)
32     WRITE(6,10) X,N,Y,XSD,YSDS
33     FORMAT(5X,'IN PRESS X=',F7.3,' N=',I3,' Y=',F7.3,' XSD=',
34     & F5.3,' YSDS=',F5.3)
35     PI=4.00*DATAN(1.00)
36     T1=NSLOTS*QSLOT/QVOID
37     IF(Y.GT.12.) GOTO 100
38     EP=DEXP(PI*Y)
39     EM=DEXP(-PI*Y)
40     EMB=DEXP(-PI*YSDS)
41     EPB=DEXP(PI*YSDS)
42
43     C
44     A1=DSIN(PI*X)*OCOSH(PI*Y)-DSIN(PI*XSD)*DCOSH(PI*YSDS)
45     A2=DCOS(PI*X)*DSINH(PI*Y)
46     A3=DCOS(PI*XSD)*DSINH(PI*YSDS)
47     A4=A1*A1+(A2-A3)**2
48     A5=A1*A1+(A2+A3)**2
49
50     C
51     G=DLOG(A4*A5)/(4.*PI)
52     WRITE(6,1)EP,EM,EMB,EPB
53     FORMAT(14,'10(1PE10.2)')
54     WRITE(6,1)G,DELX,PI,T1,A1,A2,A3,A4,A5

```

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 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

52 000514I      A8=2-EMB
53 000526I      SUM=0
54
55      C
56      C
57      C
58
59      SUM CONTRIBUION TO PRESSURE FROM EACH SLOT
60
61      DO 40 I=1,NSLOTS
62      XN=XS(I)
63      PXP=PI*(X+XN)
64      PXM=PI*(X-XN)
65      A(1)=-EP*DCOS(PXP)
66      B(1)=EP*DSIN(PXP)
67      A(2)=EM*DCOS(PXM)
68      B(2)=EM*DSIN(PXM)
69      A(3)=-EM*DCOS(PXP)
70      B(3)=EM*OSIN(PXP)
71      A(4)=EP*DCOS(PXM)
72      B(4)=EP*DSIN(PXM)
73      WRITE(6,1)A,B
74      SUM1=0
75
76      FIND THE FOUR TERMS WHICH, TOGETHER, GIVE THE PRESSURE
77
78      DO 30 J=1,4
79      A1=A(J)*A(J)+B(J)*B(J)
80      A7=A(J)-1
81      A2=A7*A7+B(J)*B(J)
82      A3=A(J)-EMB
83      A9=A3*A3+B(J)*B(J)
84      A4=ABS(9(J))
85      A5=EPB*EPB*A9
86      IF(A4,NE,0.00)A11=A4*(DATAN2(A3,A4)-DATAN2(A(J),A4))
87      IF(A4,EQ,0.00)A11=0.00
88      AA1=1.+EPB*(.5*A(J)*DLOG(A9/A1)+A11)
89      IF(A2,NE,0.00)AA2=DLOG(A2/A9)-(.5*A(J)*EMB/A1)*DLOG(A2/A5)
90      AA2=AA2*DLOG(A2)
91      IF(A4,NE,0.00)AA3=-(EMB*A4/A1)*(DATAN2(A3,A4)-DATAN2(A7,A4))
92      IF(A4,EQ,0.00)AA3=0.00
93      IF(A2,EQ,0.00)AA2=-DLOG(A9)+.5*EMB*DLOG(A5)
94      A6=AA1+AA2+AA3
95      WRITE(6,1)A1,A2,A3,A4,A5,A6,A7,A8,A9
96      C
97      C
98      SUM1=SUM1+A6
99      40 SUM=SUM+SUM1
100      PRESS=SNGL((1+T1)*G+SUM*T1/(NSLOTS*2.*PI*A8))
101      RETURN
102      100 CONTINUE
103      PRESS=SNGL(Y)
104      RETURN
105      ENO

```

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

STATEMENT BUFFER: 20 LINES/1321 BYTES      STACK SPACE: 223 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION  
DOUBLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE STRM1(NXSLOT,USLOT,W0,ZPSI,N,IMAX,XPSI,NMIN,NMAX) 1
2 C 2
3 C 3
4 C 4
5 C 5
6 C 6
7 C 7
8 C 8
9 C 9
10 C 10
11 C 11
12 C 12
13 C 13
14 C 14
15 C 15
16 C 16
17 C 17
18 C 18
19 0000041 DIMENSION USLOT(31,11),W0(11),ZPSI(31,31),XPSI(31) 19
20 C 20
21 0000041 10 FORMAT(1P5E16.6) 21
22 0000141 20 FORMAT(I10) 22
23 C 23
24 0000181 PSI(I,K,N)=USLOT(I,N)*W0(K) 24
25 C 25
26 0000001 DO 90 I=1,31 26
27 0000081 DO 80 J=1,31 27
28 0000E01 ZPSI(I,J)=0. 28
29 00011C1 ZPSI(I)=0. 29
30 C 30
31 00014C1 NX1=NXSLOT+1 31
32 00015A1 DELX = 1./NXSLOT 32
33 C 33
34 C 34
35 C 35
36 0001701 DO 100 I=1,NXSLOT 36
37 0001841 ZPSI(I,NX1)=0.0 37
38 0001AA1 100 CONTINUE 38
39 C 39
40 0001C21 ZPSI(NX1,NX1)=1.0 40
41 0001E81 XPSI(NX1)=-0.5 41
42 C 42
43 C 43
44 C 44
45 C 45
46 C 46
47 0002021 PSIMAX = 0. 47
48 00020E1 IMAX = NX1 48
49 C 49
50 00021A1 DO 200 I=NXSLOT,1,-1 50
51 0002261 IF(PSIMAX.GE.PSI(I,11,N)) GO TO 200 51

```

THE STREAM FUNCTION FOR THE BOTTOM OF THE SLOT IS PSI(X,Z)  
 DEFINED AT THE BEGINNING OF THIS PROGRAM AS PSI(I,K,N) IS  
 THE VALUE OF PSI AT THE VALUES X(I), Z(K) FOR THE NTH SLOT.  
 DETAILS SEE H. BAUM NOTES

WE WILL NEED VALUES OF (X,Z) FOR CONSTANT PSI TO CARRY OUT  
 THE VAPOR PICK-UP INTEGRALS

THESE ARE STORED IN THE (TRIANGULAR) MATRIX ZPSI(I,L)  
 LET L DEFINE A VALUE OF PSI = PSI(L,11,N)  
 LET I DEFINE AN X AND SET  
 ZPSI = Z(X) FOR THIS PARTICULAR PSI

FOR L = NX1 (CLOSED END), USLOT = 0. AND PSI = 0. FOR ALL Z  
 ALSO FOR Z = 0. (CENTER-LINE, K=0), W0 = 0. AND PSI = 0. FOR ALL X

FIND LOCATION OF MAXIMUM PSI. STREAMLINES ORIGINATE AT THE SLOT  
 WALL TO THE RIGHT OF PSIMAX AND END EITHER AT X = -1/2 OR AT  
 THE WALL BETWEEN PSIMAX AND X = -1/2.



\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

```

52 00025EI PSIMAX=PSI(I,11,N)
53 00028EI IMAX=I
54 00029AI 200 CONTINUE
55
56 C LOAD ZPSI VALUES FOR STREAMLINES WHICH LEAVE THE SLOT WALL
57 C BETWEEN X = 1/2 AND PSIMAX. WE TRACK STREAMLINES WHICH LEAVE
58 C THE SLOT WALL AT MESH POINTS, SO WE ARE INTERESTED IN INDICIES
59 C BETWEEN NSLOTS (I.E., FIRST POINT TO THE LEFT OF X = 1/2)
60 C AND LIM (POINT JUST TO THE RIGHT OF PSIMAX).
61 C
62 LIM=IMAX+1
63
64 DO 500 NN=NXSLOT,LIM,-1
65 PSICON=PSI(NN,11,N)
66 ZPSI(NN,NN)=1.0
67 XPSI(NN)=-0.5
68 IM1=NN-1
69
70 DO 400 II=IM1,1,-1
71 KFLAG = 11
72
73 DO 300 K=1,10
74 KP1=K+1
75 KM1=K-1
76 TEST1=PSI(II,K,N)
77 TEST2=PSI(II,KP1,N)
78
79 IF(PSICON.LT.TEST1) GO TO 300
80 IF(PSICON.GE.TEST2) GO TO 300
81 ZPSI(II,NN)=0.1*(FLOAT(KM1)+(PSICON-TEST1)/(TEST2-TEST1))
82 KFLAG=K
83 GO TO 301
84 CONTINUE
85 300 CONTINUE
86 301 CONTINUE
87
88 IF(KFLAG.LT.11) GO TO 400
89
90 KFLAG .GE. 11 IMPLIES NO HIT IN THE INTERPOLATION SEARCH.
91 STREAMLINE HAS RETURNED TO THE WALL BETWEEN THIS X INDEX
92 AND THE PREVIOUS ONE. INTERPOLATE TO FIND THE X LOCATION
93 OF THE STREAMLINE - WALL INTERSECTION.
94
95 IIP1=II + 1
96 IIM1=II - 1
97 TEST1=PSI(II,11,N)
98 TEST2=PSI(IIP1,11,N)
99 XPSI(NN)=-0.5+DELX*(FLCAT(IIM1)+(PSICON-TEST1)/(TEST2-TEST1))
100 GO TO 401
101 CONTINUE
102 400 CONTINUE
103 401 CONTINUE

```

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```

103 000574I 500 CONTINUE 103
104 C 104
105 00058CI ZPSI(IMAX,IMAX)=1.0 105
106 000582I XPSI(IMAX)=-0.5+DELX*(IMAX-1) 106
107 C 107
108 C IF N=NMIN OR NMAX WE WANT TO SAVE ZPSI AND XPSI FOR LATER PLOTS 108
109 C WRITE ZPSI(I,N) AND XPSI(I) TO DISK FILE 109
110 C 110
111 00050CI IF(N.EQ.NMIN) GO TO 60C 111
112 0005F4I IF(N.EQ.NMAX) GO TO 60C 112
113 00060CI GO TO 1001 113
114 C 114
115 000612I 600 CONTINUE 115
116 000612I WRITE(7,20) IMAX 116
117 000630I IMIN=1 117
118 000638I IMX=5 118
119 000640I 700 DO 800 J=1,NX1 119
120 000654I WRITE(7,10) (ZPSI(I,J),I=IMIN,IMX) 120
121 0006E8I 800 CONTINUE 121
122 000700I IF(IMX.GE.NX1) GO TO 90C 122
123 000718I IMIN=IMIN+5 123
124 000726I IMX=IMX+5 124
125 000734I IF(IMX.GT.NX1) IMX=NX1 125
126 000752I GO TO 700 126
127 000756I 900 CONTINUE 127
128 C 128
129 000756I DO 1000 J=1,NX1 129
130 00076AI WRITE(7,10) XPSI(J) 130
131 0007A4I 1000 CONTINUE 131
132 00078CI 1001 CONTINUE 132
133 C 133
134 00078CI RETURN 134
135 0007C2I END 135

```

NO ERRORS:F7D R04-00 SUBROUTINE STRM1 06/24/81 08:21:38 TABLE SPACE: 3 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 167 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE PICUP1(NXSLOT,ZPSI,XPSI,USLOT,W0,UB0,TOTAL,N,IMAX)
2 C
3 C THIS FORMS THE INTEGRAL ALONG LINES OF CONSTANT PSI OF
4 C DL/Q
5 C WHERE Q**2 = (UB0*USLOT(I,N))**2 + (W0*UP)**2
6 C UP = FUNCTION DEFINED BELOW, IT IS THE DERIVATIVE OF USLOT
7 C WITH RESPECT TO X EVALUATED AT Y = 0.
8 C NOTE THAT UP IS SINGULAR FOR X = -0.5
9 C THIS WILL MAKE THE INTEGRAND, 1/Q = 0. SO THERE
10 C WILL BE NO CONTRIBUTION TO THE INTEGRAL FOR THIS
11 C X VALUE.
12 C RECALL THAT W0 = 0. FOR Z = 0.
13 C UBC = 0. FOR Z = 1.
14 C THE INTEGRALS ARE RETURNED IN SUM(J)
15 C REF: H.BAUM NOTES: STRONG SLOT, PAGES 42,46,47 AND
16 C UNNUMBERED SHEET. NOTE THAT I1 OF THIS SHEET IS NOT
17 C INCLUDED IN THIS VERSION.
18 C
19 C WE HAVE ZPSI(I,K) = Z FOR FIXED PSI, X IMPLIED FROM I AND PSI FROM K
20 C
21 C WE WILL FORM INTEGRALS FOR THE STREAMLINES ORIGINATING AT MESH POINTS
22 C BEGINNING AT THE BACK OF THE SLOT AND WORKING TOWARD TO OPEN END
23 C STOPPING EITHER AT THE MESH POINT WHERE THE STREAM FUNCTION IS A
24 C MAXIMUM OR AT THE END OF THE SLOT. IN THE LATTER CASE, NOTE THAT
25 C THERE WOULD BE ONLY ONE POINT FOR ZPSI(I,1) AND THIS INTEGRAL
26 C WOULD BE 0 BECAUSE THE PATH LENGTH WOULD BE 0, I.E. SUM(1) = 0.
27 C
28 C DIMENSION ZPSI(31,31),USLOT(31,11),W0(11),UB0(11),SUM(30)
29 C &,TOTAL(11),XPSI(31)
30 C
31 C PSI(I,K,N) = USLOT(I,N)*W0(K)
32 C UP(X) = SQRT(2./(1+SIN(PI*X)))
33 C
34 C PI = 3.141592654
35 C NX1=NXSLOT + 1
36 C DX = 1./FLOAT(NXSLOT)
37 C LIM=IMAX+1
38 C
39 C DO 100 J=1,NX1
40 C SUM(J) = 0.
41 C 100 CONTINUE
42 C
43 C START INTEGRAL AT SLOT WALL, Z = 1., AND INTEGRATE
44 C TOWARD X = -0.5
45 C NOTE: THE STAGNATION STREAMLINE, J = NX1, IS TREATED SPECIALLY
46 C INDEX J (BELOW) REFERS TO THE STREAMLINE
47 C INDEX I REFERS TO THE X LOCATION OF THE INTEGRAND TERM
48 C BEING FORMED.
49 C
50 C SUM(IMAX)=0.
51 C

```

```

52 00028CI      DO 300 J=LIM,NXSLOT      52
53 0002A4I      JM1=J-1                  53
54 000282I      W=W0(11)                 54
55 0002C2I      X=DX*JM1-0.5             55
56 0002DCI      Q=ABS(W*UP(X))           56
57 00031AI      TERM1 = 1./Q              57
58                                     58
59      C      FORM THE NEXT INTEGRAND VALUE ALONG THE STREAMLINE 59
60      C      IFLAG=0                    60
61 00032CI      DO 200 I=JM1,1,-1        61
62      C      IM1=I-1                    62
63 000334I      IP1=I+1                    63
64 000340I      X=DX*IM1-0.5             64
65 00034EI      Q=ABS(W*UP(X))           65
66 00035CI      IF(X.GE.XPSI(J)) GO TO 180 66
67 000376I      C      FAILURE OF THE ABOVE TEST TELL US THAT 67
68      C      STREAMLINE HAS REACHED THE WALL TO THE RIGHT OF THE 68
69      C      CURRENT POINT. IN THIS CASE THE TERM BECOMES 69
70      C      W=W0(11)                    70
71      C      Q=ABS(W*UP(XPSI(J)))        71
72      C      TERM2=1./Q                  72
73 00039CI      DZ=1.0-ZPSI(IP1,J)        73
74 0003ACI      DEL=XPSI(J)-(-0.5+DX*I)   74
75 000402I      DL=SQRT(DEL**2+DZ**2)     75
76 000414I      SUM(J)=SUM(J) + (TERM1 + TERM2)*DL*0.5 76
77 000440I      GO TO 201                 77
78 000470I      C      GO TO 201          78
79 00048AI      C      GO TO 201          79
80 0004EAI      C      GO TO 201          80
81      C      GO TO 201                  81
82 0004FOI      C      GO TO 201          82
83 0004FOI      C      GO TO 201          83
84      C      GO TO 201                  84
85      C      GO TO 201                  85
86      C      GO TO 201                  86
87      C      GO TO 201                  87
88      C      GO TO 201                  88
89      C      GO TO 201                  89
90      C      GO TO 201                  90
91      C      GO TO 201                  91
92      C      GO TO 201                  92
93      C      GO TO 201                  93
94      C      GO TO 201                  94
95      C      GO TO 201                  95
96      C      GO TO 201                  96
97      C      GO TO 201                  97
98      C      GO TO 201                  98
99      C      GO TO 201                  99
100      C      GO TO 201                  100
101      C      GO TO 201                  101
102      C      GO TO 201                  102

```



FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

103 000786I      TERM2 = 1./Q      103
104 000798I      DZ = ZPSI(IP1,J)-ZPSI(I,J)      104
105 0007DEI      DL = SQRT(DX**2 + DZ**2)      105
106 00082AI      SUM(J)=SUM(J) + (TERM1 + TERM2)*DL*0.5      106
107 00085AI      TERM1=TERM2      107
108 000866I      200 CONTINUE      108
109 00087CI      201 CONTINUE      109
110      C      110
111 00087CI      300 CONTINUE      111
112      C      112
113      C      113
114      C      114
115 000894I      J=NX1      115
116 0008A0I      SUM(J)=0.      116
117 000882I      DZ=0.1      117
118 00089EI      X=0.5      118
119 0008CAI      Q=ABS(W0(11)*UP(X))      119
120 00090AI      TERM1=1./Q      120
121      C      121
122 00091CI      DO 400 K=10,2,-1      122
123 000924I      Q=SQRT((UB0(K)*USLOT(NX1,N))**2+(W0(K)*UP(X))**2)      123
124 0009C6I      TERM2=1./Q      124
125 0009D8I      SUM(J)=SUM(J)+(TERM1+TERM2)*DZ*0.5      125
126 000A08I      TERM1=TERM2      126
127 000A14I      400 CONTINUE      127
128      C      128
129 000A2AI      DL=SQRT(DX**2+DZ**2)      129
130 000A76I      I=NXSLOT      130
131 000A82I      Q=ABS(UB0(1)*USLOT(I,N))      131
132 000ACEI      TERM2=1./Q      132
133 000AE0I      SUM(J)=SUM(J)+(TERM1+TERM2)*DL*0.5      133
134 000B10I      TERM1=TERM2      134
135 000B1CI      II=NXSLOT - 1      135
136      C      136
137 000B2AI      DO 450 I=II,1,-1      137
138 000B36I      Q=ABS(UB0(1)*USLOT(I,N))      138
139 000B82I      TERM2=1./Q      139
140 000B94I      SUM(J)=SUM(J)+(TERM1+TERM2)*DX*0.5      140
141 000BC4I      TERM1=TERM2      141
142 000BD0I      450 CONTINUE      142
143      C      143
144      C      144
145      C      145
146      C      146
147      C      147
148 000BE6I      E=2./3.      148
149 000BF2I      TOTAL(N)=0.      149
150 000C0CI      PSI1=PSI(NX1,11,N)      150
151 000C38I      TERM1=(SUM(NX1))**E      151
152      C      152
153 000C56I      DO 500 J=NXSLOT,IMAX,-1      153

```

THE TOTAL MASS PICK-UP IS TWICE THE INTEGRAL OF SUM(K)  
 TWICE BECAUSE WE INTEGRATE THE SYMETRIC FUNCTION FROM  
 THE CENTER-LINE TO ONE EDGE.

FORTRAN VIIO: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

154 000C6EI      PSI2=PSI(J,11,N)      154
155 000C98I      DPSI=PSI2-PSI1        155
156 000CAAI      TERM2=(SUM(J))**E     156
157 000CC8I      TOTAL(N)=TOTAL(N)+(TERM1+TERM2)*DPSI 157
158 000D02I      PSI1=PSI2            158
159 C            WRITE(6,1000) TOTAL(N),TERM1,TERM2,DPSI 159
160 00000EI      TERM1=TERM2           160
161 000D1AI      500 CONTINUE          161
162 C            C1000 FORMAT(10X,'TOTAL =',1P4E15.6) 162
163 163          163                    163
164 000D32I      RETURN                 164
165 C            C                        165
166 000D38I      END                     166

```

```

NO  ERRORS:F7D R04-00  SUBROUTINE PICUP1 06/24/81 08:23:08  TABLE SPACE: 4 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES  STACK SPACE: 214 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE PRINT1(XSLOT,NXSLOT,USLOT,XS,NSLOTS,XL,
2      & WO,TOTAL)
3
4      C
5      C THIS PRINTS RESULTS FOR THE INTERCONTAINER SLOTS
6
7      C DIMENSION USLOT(31,11),XS(11),
8      & WO(11),TOTAL(11)
9
10     DATA BLANK/'.'/
11
12     C PSI(I,K,N)=USLOT(I,N)*WO(K)
13
14     C
15     C 5 FORMAT(1H1,///,10X,'INTERCONTAINER SLOT RESULTS')
16     C 20 FORMAT(///,10X,'INTERCONTAINER SLOT VELOCITY - U')
17     C 40 FORMAT(F9.4,2X,1P11E10.3)
18     C 50 FORMAT(///,4X,'X\LOC=' ,1P11E10.2)
19     C 55 FORMAT(1X,A1)
20     C 60 FORMAT(///,10X,'INTERCONTAINER SLOT BOTTOM STREAM FUNCTION',
21     & ///,10X,'FOR SLOT AT LOCATION X =',F6.2)
22     C 70 FORMAT(///,4X,'X\Z=' ,1P11E10.2)
23     C 90 FORMAT(///,10X,'DIMENSIONLESS MASS PICK-UP',///,
24     & 1CX,'SLOT LOCATION MASS PICK-UP',///)
25     C 91 FORMAT(F15.2,7X,1PE15.5)
26
27     C WRITE(6,5)
28
29     C
30     C DELX=1./NXSLOT
31     C NX1=NXSLOT+1
32     C XINC=DELX * XSLOT
33     C X=-0.5*XSLOT-XINC
34     C WRITE(6,20)
35     C WRITE(6,50) (XL*XS(I),I=1,NSLOTS)
36     C WRITE(6,55) BLANK
37     C DO 220 I=1,NX1
38     C X=X+XINC
39     C WRITE(6,40) X,(USLOT(I,J),J=1,NSLOTS)
40     C CONTINUE
41
42     C 220 CONTINUE
43
44     C DO 600 N=1,NSLOTS
45     C X1=XS(N)*XL
46     C X=-0.5*XSLOT-XINC
47     C WRITE(6,60) X1
48     C WRITE(6,70) (0.1*I,I=0,10)
49     C WRITE(6,55) BLANK
50     C DO 500 I=1,NX1
51     C X=X+XINC
52     C WRITE(6,40) X,(PSI(I,K,N),K=1,11)
53     C CONTINUE
54
55     C 500 CONTINUE
56
57     C 600 CONTINUE
58
59     C
60     C 0005061
61
62     C 51

```

FORTAN-VIID R04-00

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

FORTAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

```

52 0005EEI      WRITE(6,90)
53 000608I      DO 700 I=1,NSLOTS
54 00061CI      WRITE(6,91) XS(I),TOTAL(I)
55 000674I      700 CONTINUE
56              C
57 00068CI      RETURN
58 000692I      END

```

TABLE SPACE: 3 KB

NO ERRORS:F7D R04-00 SUBROUTINE PRINT1 06/24/81 08:27:25  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 136 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001      SUBROUTINE PRINT(UB,UB0,W,W0)
2
3      C
4      C      THIS PRINTS RESULTS FOR THE MAIN VOID AND THE
5      C      LOCATION INDEPENDENT VARIABLES UB,UB0,W, AND W0
6      C
7      C      DIMENSION UB(10,11),UB0(11),W(10,11),W0(11),ZZ(11)
8
9      C      DATA BLANK/'.'/
10
11      C
12      C      FORMAT(1H1,///,10X,'GEOMETRY INDEPENDENT RESULTS')
13      C      FORMAT(///,10X,'FIELD OF UB')
14      C      FORMAT(///,10X,'FIELD OF UB0')
15      C      FORMAT(F9.4,2X,1P11E10.2)
16      C      FORMAT(///,4X,'Y\Z=' ,1P11E10.2)
17      C      FORMAT(1X,A1)
18      C      FORMAT(////)
19      C      FORMAT(///,10X,'FIELD OF W = INDEFINATE Z INTEGRAL OF UB')
20      C      FORMAT(///,10X,'FIELD OF W0 = INDEFINATE Z INTEGRAL OF UB0')
21
22      C      WRITE(6,5)
23
24      C
25      C      DO 550 I=1,11
26      C      ZZ(I)=0.1*(I-1)
27      C      CONTINUE
28
29      C
30      C      WRITE(6,18)
31      C      WRITE(6,50) (ZZ(I),I=1,11)
32      C      WRITE(6,55) BLANK
33
34      C
35      C      DO 600 I=1,10
36      C      Y=0.1*I
37      C      WRITE(6,20) Y,(UB(I,J),J=1,11)
38      C      CONTINUE
39
40      C
41      C      Y=0.05
42      C      WRITE(6,19)
43      C      WRITE(6,50) (ZZ(I),I=1,11)
44      C      WRITE(6,55) BLANK
45      C      WRITE(6,20) Y,(UB0(I),I=1,11)
46      C      WRITE(6,70)
47      C      WRITE(6,50) (ZZ(I),I=1,11)
48      C      WRITE(6,55) BLANK
49
50      C
51      C      DO 700 I=1,10
52      C      Y=0.1*I
53      C      WRITE(6,20) Y,(W(I,J),J=1,11)
54      C      CONTINUE
55
56      C
57      C      WRITE(6,80)
58      C      WRITE(6,50) (ZZ(I),I=1,11)
59      C      WRITE(6,55) BLANK
60
61      C
62      C      WRITE(6,121)
63
64      C
65      C      WRITE(6,121)
66
67      C
68      C      WRITE(6,121)
69
70      C
71      C      WRITE(6,121)
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73      C
74      C      WRITE(6,121)
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77      C      WRITE(6,121)
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95      C      WRITE(6,121)
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991     C
992     C      WRITE(6,121)
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994     C
995     C      WRITE(6,121)
996
997     C
998     C      WRITE(6,121)
999
1000    C

```

FORTRAN-VIIO R04-00

FORTRAN VIIO: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

52 000630I      Y=0.05
53 000630I      WRITE(6,20) Y,(W0(J),J=1,11)
54          C
55 000686I      WRITE(6,60)
56          C
57 0006D0I      RETURN
58 0006D6I      END

```

TABLE SPACE: 2 KB

NO ERRORS:F7D R04-00 SUBROUTINE PRINT 06/24/81 08:28:26  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 133 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

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58

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE INPUT1(DIFFU,CO,TK,NFLOWS)
2
3 C INPUT DATA FOR EACH CASE IN ORDER OF ENTRY
4 C REPEAT FOR EACH CASE UP TO NCHEMS
5 C
6 C CASE TITLE, 80 ALPHAMERIC CHARACTERS MAX
7 C DIFFU = MASS DIFFUSIVITY OF SPILL VAPOR IN AIR AT 0 DEG C.
8 C CM**2/SEC
9 C WM = MOLECULAR WEIGHT OF SPILL CHEMICAL
10 C B = MATERIAL DEPENDENT EMPIRICAL CONSTANT, 8 OF ANTON'S FORMULA, DEG K
11 C T1 = TEMPERATURE, DEG C, AT WHICH SPILL CHEMICAL HAS A VAPOR
12 C PRESSURE OF 1 ATMOS.
13 C T2 = REFERENCE TEMPERATURE, C OF ANTON'S FORMULA
14 C TC = AMBIENT TEMPERATURE, DEGREES C
15 C NFLOWS= NUMBER OF VENTELATION FLOW RATES TO BE INCLUDED.
16 C
17 0000041 DIMENSION TITLE(80)
18 C
19 0000041 FORMAT(80A1)
20 0000101 FORMAT(///,10X,80A1)
21 00001C1 FORMAT(6F10.2)
22 0000241 FORMAT(I10)
23 0000281 FORMAT(///,10X,TC =,F5.1, DEC C',10X,CO =,F7.2, GM/M**3',
24 + 10X,P =,F6.2, MM HG')
25 C
26 0000661 READ(5,5) TITLE
27 0001CC1 WRITE(6,8) TITLE
28 0001F01 TOK = 273.16
29 0001FC1 READ(5,10) DIFFU,WM,8,T1,T2,TC
30 C
31 0002301 TKA = T2 + TC
32 0002421 TKA1= T2 + T1
33 0002541 T = TC + TOK
34 0002661 C=1.0E-4
35 0002721 E=1.81
36 00027E1 DIFFU=DIFFU*C*(T/TOK)**E
37 0002861 CO = 44.613*WM*(TOK/T)*EXP(8*(TKA-TKA1)/(TKA1*TKA))
38 0003141 PP = 760.*EXP(8*(TKA-TKA1)/(TKA1*TKA))
39 00035C1 WRITE(6,30) TC,CO,PP
40 C
41 0003841 READ(5,20) NFLOWS
42 C
43 0003A41 RETURN
44 C
45 0003AA1 END

```

NO ERRORS:F7D R04-00 SUBROUTINE INPUT1 06/24/81 08:29:30 TABLE SPACE: 2 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 124 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-Q184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 000000I      SUBROUTINE INPUT2(Q0)
2      C
3      C      Q0 = MAIN VOID SINK STRENGTH, M**3/SEC
4      C
5 000004I      10  FORMAT (F10.2)
6      C
7 000010I      READ(5,10) Q0
8 000030I      RETURN
9 000036I      END

```

NO ERRORS:F70 R04-00 SUBROUTINE INPUT2 06/24/81 08:30:25 TABLE SPACE: 1 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 47 WORDS



FORTAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE PPLOT(XS,NMIN,NMAX,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,
2      & YSD,QVOID,QSLOT,NSLOTS,NXSLOT)
3
4 C
5 C WE WANT TO PLOT SLOT END PRESSURES FOR SLOTS N=NMIN AND N=NMAX.
6 C THIS WILL BE DONE BY A SEPARATE PROGRAM USING PRESSURE VALUES
7 C STORED IN A DISK FILE.
8 C THE CALL TO PPLOT IS TO BUILD THIS DISK FILE.
9
10 DIMENSION XS(11)
11
12 FORMAT(1P3E15.6)
13
14 FORMAT(5I5,1P4E15.6)
15
16 YB(Y)=FSSLOT*XSLT*Y/(FS*XL)
17 PL(Y)=QVOID*DSL3*FSSLOT*PRESS(XS,N,YB(Y),XSD,YSDS,
18      & QVOID,QSLOT,NSLOTS)/(QSLOT*D3*FS)
19
20 PUT HEADER INFORMATION ON PRESSURE PLOT FILE
21
22 NYS=100
23 NYSP1=NYSP1
24 WRITE(8,20) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XS(NMIN),XS(NMAX),
25      & XSD,YSD
26
27 Y=0
28 DELY=1./FLOAT(NYS)
29 YSDS=YB(YSD)
30
31 DO 400 I=1,NYSP1
32 TEST=Y+DELY
33 IF(Y.LT.YSD.AND.TEST.GE.YSD) GO TO 450
34 N=NMIN
35 PMIN=PL(Y)
36 N=NMAX
37 PMAX=PL(Y)
38 WRITE(8,10) Y,PMIN,PMAX
39 GO TO 490
40
41 CONTINUE
42 TEST1=YSD-0.001
43 TEST2=YSD+0.001
44 N=NMIN
45 PMIN=PL(TEST1)
46 N=NMAX
47 PMAX=PL(TEST2)
48 WRITE(8,10) TEST1,PMIN,PMAX
49 N=NMIN
50 PMIN=PL(TEST2)
51 N=NMAX
52 PMAX=PL(TEST2)
53 WRITE(8,10) TEST2,PMIN,PMAX
54
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57
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FORTRAN-VIID R04-00

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

52  
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52 000444I 490 CONTINUE  
53 000444I Y=Y+DELY  
54 000444I  
55 000456I 400 CONTINUE  
56 00046EI RETURN  
57 000474I END

TABLE SPACE: 2 KB

NO ERRORS:F7D R04-00 SUBROUTINE PLOT 06/24/81 08:31:23  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 110 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 FUNCTION PRESS(XS,N,Y,XSD,YSDS,QVOID,QSLOT,NSLOTS)
2
3 C WRITTEN BY D. CORLEY, MAY 1979
4 C
5 C NOTATION FOLLOWS H. BAUM
6 C
7 0000181 DIMENSION A(4),B(4),XS(11)
8 C
9 C NSLOTS SLOTS AND 1 MAIN VOID, (NSLOTS+1) IN ALL
10 X,Y ARE DIMENSIONLESS POSITION OF POINT WHERE PRESSURE IS NEEDED
11 XSD,YSDS ARE DIMENSIONLESS POSITION OF SOURCE
12 QSLOT ARE VOL FLUX INTO INTERCONTAINER SLOTS
13 QVOID IS VOL FLUX INTO MAIN VOID
14 X GOES FROM -.5 TO +.5
15 Y GOES FROM 0 TO (INFINITY)
16 THE SLOTS ARE LOCATED AT POSITIONS XS
17 WE ARE INTERESTED IN THE SLOT AT XS(N).
18
19 0000181 X=XS(N)
20 WRITE(6,10) X,N,Y,XSD,YSDS
21 C10 FORMAT(5X,'IN PRESS X=',F7.3,' N=',I3,' Y=',F7.3,' XSD=',
22 8 F5.3,' YSDS=',F5.3)
23 PI=4.*ATAN(1.)
24 T1=NSLOTS*QSLOT/QVOID
25 IF(Y.GT.12.) GOTO 100
26 EP=EXP(PI*Y)
27 EM=EXP(-PI*Y)
28 EMB=EXP(-PI*YSDS)
29 EPB=EXP(PI*YSDS)
30 C
31 000181 A1=SIN(PI*X)*COSH(PI*Y)-SIN(PI*XSD)*COSH(PI*YSDS)
32 000260 A2=COS(PI*X)*SINH(PI*Y)
33 0002C4I A3=COS(PI*XSD)*SINH(PI*YSDS)
34 000328I A4=A1*A1+(A2-A3)**2
35 000352I A5=A1*A1+(A2+A3)**2
36 C
37 00037CI G=ALOG(A4*A5)/(4.*PI)
38 WRITE(6,1) EP,EM,EPB
39 000398I 1 FORMAT(1H,10(1PE10.2))
40 C WRITE(6,1)G,DELX,PI,T1,A1,A2,A3,A4,A5
41 0003CCI A8=2-EMB
42 0003DEI SUM=0
43 C
44 C SUM CONTRIBUTION TO PRESSURE FROM EACH SLOT
45 C
46 0003EAI DO 40 I=1,NSLOTS
47 0003FEI XN=XS(I)
48 000418I PXP=PI*(X+XN)
49 000430I PXM=PI*(X-XN)
50 000448I A(1)=-EP*COS(PXP)
51 000472I B(1)=EP*SIN(PXP)

```

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

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52 000492I      A(2)=EM*COS(PXM)
53 000482I      B(2)=EM*SIN(PXM)
54 000402I      A(3)=-EM*COS(PXP)
55 0004FAI      B(3)=EM*SIN(PXP)
56 00051AI      A(4)=EP*COS(PXM)
57 00053AI      B(4)=EP*SIN(PXM)
58      C      WRITE(6,1)A,B
59      SUM1=0
60
61      C      FIND THE FOUR TERMS WHICH, TOGETHER, GIVE THE PRESSURE
62
63      DO 30 J=1,4
64      A1=A(J)*A(J)+8(J)*8(J)
65      A7=A(J)-1
66      A2=A7+A7+8(J)*8(J)
67      A3=A(J)-EMB
68      A9=A3+A3+8(J)*8(J)
69      A4=ABS(8(J))
70      A5=EP8*EP8*A9
71      IF(A4.NE.0.)A11=A4*(ATAN2(A3,A4)-ATAN2(A(J),A4))
72      IF(A4.EQ.0.)A11=0.
73      AA1=1.+EP8*(.5*A(J)*ALOG(A9/A1)+A11)
74      IF(A2.NE.0.)AA2=ALOG(A2/A9)-(C.5*A(J)*EMB/A1)*ALOG(A2/A5)
75      -.5*A8*ALOG(A2)
76      IF(A4.NE.0.)AA3=- (EMB*A4/A1)*(ATAN2(A3,A4)-ATAN2(A7,A4))
77      IF(A4.EQ.0.)AA3=0.
78      IF(A2.EQ.0.)AA2=-ALOG(A9)+.5*EMB*ALOG(A5)
79      A6=AA1+AA2+AA3
80      C      WRITE(6,1)A1,A2,A3,A4,A5,A6,A7,A8,A9
81      C      WRITE(6,1)AA1,AA2,AA3,A11
82      SUM1=SUM1+A6
83      SUM=SUM+SUM1
84      PRESS=(1+T1)*G+SUM*T1/(NSLOTS*2.*PI*A8)
85      RETURN
86      C      100 CONTINUE
87      PRESS=Y
88      RETURN
89      END
WARNING # 301 *****
>>> UNREFERENCED LABEL
      SYMBOL/LABEL = 1
      <<<

```

NO ERRORS:F7D R04-00 FUNCTION PRESS 06/24/81 08:32:35 TABLE SPACE: 3 K9  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 223 WORDS  
 SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1  33ATCH
2  C
3  C
4  C
5  C
6  C
7  C
8  C
9  C
10 C
11 C
12 C
13 C
14 C
15 0000001
16 & ,IMAX(2)
17 C
18 000006I
19 00001AI
20 00004AI
21 00004AI
22 00004EI
23 00008EI
24 00008CI
25 00009AI
26 0000A4I
27 0000E4I
28 000120I
29 000120I
30 000120I
31 C
32 C
33 C
34 000124I
35 00251CI
36 00253CI
37 C
38 002544I
39 002544I
40 C
41 C
42 C
43 002552I
44 002590I
45 C
46 C
47 C
48 0025D0I
49 0025F0I
50 C
51 C

PROGRAM TO READ DATA FROM DISK FILES AND PREPARE PLOTS

TWO SETS OF PLOTS ARE DRAWN
SLOT END PRESSURE VERSUS HEIGHT FOR TWO SLOTS:
1) THE SLOT FURTHEST FROM THE SUCTION
2) THE SLOT CLOSEST TO THE SUCTION
THESE ARE DRAWN BY SUBROUTINE PLOTSP

SLOT BOTTOM STREAMLINES. FOR THESE THE TRANSVERSE
SCALE IS EXAGGERATED RELATIVE TO THE LENGTH SCALE
BY A FACTOR OF 10.
THESE ARE DRAWN BY SUBROUTINE PLOTST

DIMENSION Y(103),P1(103),P2(103),ZPSI(31,31,2),XPSI(31,2)
& ,IMAX(2)

FORMAT(5I5,1P4E15.6)
FORMAT(5X,'ENTER DELT FOR CASE',IS,'', FORMAT F5.3')
FORMAT(F5.3)
FORMAT(I5)
FORMAT(5X,'ENTER NUMBER OF CASES TO BE PLOTTED, FORMAT I5')
FORMAT(1P3E15.6)
FORMAT(4I5,1P4E15.6)
FORMAT(1P5E16.6)
FORMAT(10X,'NUMBER OF PRESSURE POINTS READ =',IS,/,
& 10X,'NUMBER EXPECTED =',IS)
FORMAT(10X,'NUMBER OF XPSI POINTS READ =',IS,/,
& 10X,'NUMBER EXPECTED =',IS)
FORMAT(I10)

READ NUMBER OF CASES TO BE PROCESSED

WRITE(9,18)
READ(5,15) NGEOMS
NGEOM=0

CONTINUE
NGEOM= NGEOM + 1

READ HEADER INFORMATION FOR PRESSURE DATA

READ(8,10) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XSDMIN,XSDMAX,XSD,YSD
WRITE(6,10) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XSDMIN,XSDMAX,XSD,YSD

ENTER DELT

WRITE(9,12) NGEOM
READ(5,13) DELT

READ PRESSURE DATA

```

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\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

52      C
53      002610I      NYSP1=NYSP+1
54      002611E      NYSP2=NYSP+2
55      002620I      DO 200 I=1,NYSP2
56      002640I      N=I
57      002641I      READ(8,20,ERR=300) Y(I),P1(I),P2(I)
58      002660I      CONTINUE
59      002661I      200 CONTINUE
60      002662I      300 CONTINUE
61      002663I      WRITE(6,50) N,NYSP2
62      C
63      C      READ HEADER INFORMATION FOR STREAMLINE DATA
64      C
65      002718I      READ(7,30) NXSLCT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK
66      002754I      WRITE(6,30) NXSLCT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK
67      C
68      C      READ STREAMLINE DATA
69      C
70      002790I      NX1=NXSLCT+1
71      002791E      M=0
72      002792I      400 M=M+1
73      002793I      READ(7,70) IMAX(M)
74      002794I      IMIN=1
75      002795I      IMX=5
76      002796I      500 DO 600 J=1,NX1
77      002797I      READ(7,40) (ZPSI(I,J,M),I=IMIN,IMX)
78      002798I      CONTINUE
79      002799I      IF(IMX.GE.NX1) GO TO 700
80      002800I      IMIN=IMIN+5
81      002801I      IMX=IMX+5
82      002802I      IF(IMX.GT.NX1) IMX=NX1
83      002803I      GO TO 500
84      002804I      700 CONTINUE
85      C
86      002910I      DO 800 J=1,NX1
87      002911E      N=J
88      002912I      READ(7,40,ERR=900) XPSI(J,M)
89      002913I      CONTINUE
90      002914I      800 CONTINUE
91      002915I      900 CONTINUE
92      002916I      WRITE(6,60) N,NX1
93      002917I      IF(M.EQ.1) GO TO 400
94      C
95      C      PREPARE PRESSURE PLOTS
96      C
97      002920I      CALL PLOTP(NYSP,Y,P1,P2,NMIN,NMAX,XSD,YSD,DELT)
98      C
99      C      PREPARE STREAMLINE PLOTS
100      C
101      002923I      CALL PLOTST(NXSLCT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK,
102      & ZPSI,XPSI,IMAX,DELT)
103      C
104      C      LOOP BACK TO LINE 100 FOR NEXT CASE AS NEEDED

```

FORTRAN VIIO: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

103      C
104      002A48I      IF(NGEOMS.GT.NGEOM) GO TO 100
105      C
106      002A5EI      CALL DRAW(0,0,0,9999)
107      C
108      002AA4I      END

```

NC ERRORS:F7D R04-00 MAINPROG .MAIN 06/24/81 08:40:23 TABLE SPACE: 4 KB  
 STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 133 WORDS

FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1 0000001 SUBROUTINE PLOTP(NYS,Y,P1,P2,NMIN,NMAX,XSD,YSD,DELT)
2 C
3 C TO PLOT SLOT END PRESSURES, P1(Y), SLOT CLOSEST TO THE SUCTION
4 C AND P2(Y), SLOT FURTHEST FROM THE SUCTION.
5 C
6 0000041 DIMENSION Y(103),P1(103),P2(103)
7 C
8 0000041 NYS2=NYS+2
9 0000261 SAME = 9999.
10 0000321 CALL SCAN(P1,Y,-NYS2,440)
11 0000901 CALL DRAW(P1,Y,NYS2,441)
12 0000E01 CALL DRAW(P2,Y,NYS2,6443)
13 0001301 CALL AXES(26.2,'P (DIMENSIONLESS PRESSURE)',24.1,
14 & 'Y (DIMENSIONLESS HEIGHT)')
15 0001CC1 CALL MODE(5,SAME,SAME,SAME)
16 0001F81 CALL NOTE(2.0,7.7,'DELT =',6)
17 00026C1 CALL NOTE(2.7,7.7,'DELT,1002)
18 0002801 CALL NOTE(2.0,7.4,'XSD =',5)
19 0003241 CALL NOTE(2.6,7.4,'XSD,1003)
20 0003681 CALL NOTE(3.1,7.4,'YSD =',7)
21 0003DC1 CALL NOTE(3.9,7.4,'YSD,1003)
22 0004201 CALL NOTE(2.0,7.0,'LINE = SLOT',11)
23 0004941 CALL NOTE(3.3,7.0,NMIN,0)
24 0004D81 CALL NOTE(2.0,6.8,'DOTS = SLOT',11)
25 00054C1 CALL NOTE(3.3,6.8,NMAX,0)
26 0005901 CALL DRAW(0.0,1,9000)
27 0005DC1 RETURN
28 0005E21 END

```

NO ERRORS:F7D R04-00 SUBROUTINE PLOTP 06/24/81 08:40:35 TABLE SPACE: 3 KB  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 59 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION



FORTRAN VIIC: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 \*\*\* SEE DOCUMENTATION PACKAGE, 04-101M99.

```

1  0000001  SUBROUTINE PLOTST(NXSLOT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK,
2      & ZPSI,XPSI,IMAX,DELT)
3
4      C
5      C      TO PLOT STREAMLINES FOR THE SLOT BOTTOM FOR SLOTS
6      C      NMIN = SLOT CLOSEST TO THE SUCTION
7      C      NMAX = SLOT FURTHEST FROM THE SUCTION
8      C
9      C      DIMENSION ZPSI(31,31,2),XPSI(31,2),X(31),Z(31),IMAX(2),NM(2)
10     C
11     C      WE WILL FORM A PAIR OF VECTORS, X(I) AND Z(I) TO BE PLOTTED.
12     C      THE PSI = 0. STREAMLINES SETS THE SCALE FOR THE PLOT, DO
13     C      IT FIRST.
14     C
15     C      NM(1)=NMIN
16     C      NM(2)=NMAX
17     C      SAME = 9999.
18     C      NX1=NXSLOT+1
19     C      DX = 1./FLOAT(NXSLOT)
20     C      M=0
21     C      M=M+1
22     C      LIM=IMAX(M)+1
23     C
24     C      LOAD DATA FOR STAGNATION STREAMLINE. THIS WILL SET THE
25     C      SIZE OF THE PLOT WHEN CALL SCAN IS USED BELOW.
26     C
27     C      X(1) = 0.5
28     C      Z(1) = 1.
29     C
30     C      DO 100 I=2,NX1
31     C      X(I) = 0.5 - DX*FLOAT(I-1)
32     C      Z(I) = C.0
33     C      100 CONTINUE
34     C
35     C      CALL SCAN(Z,X,-NX1,440)
36     C      CALL MODE(2, 7.0,SAME, SAME)
37     C      CALL MODE(3, 9.0,SAME, SAME)
38     C      CALL MODE(8,-1.75, 0.5, 0.0)
39     C      CALL MODE(9,-0.8,0.20, 0.0)
40     C      CALL DRAW(Z,X,NX1,441)
41     C      DO 120 I=1,NX1
42     C      Z(I)=-Z(I)
43     C      120 CONTINUE
44     C      CALL DRAW(Z,X,NX1,441)
45     C
46     C      NOW PROCEED TO THE OTHER STREAMLINES
47     C      CODING FOLLOWS CLOSELY THAT OF PICUP1.FTN
48     C
49     C      INDEX J (BELOW) REFERS TO THE STREAMLINE
50     C      INDEX I REFERS TO THE X LOCATION OF THE INTEGRAND TERM
51     C      BEING FORMED.

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52 00041CI      DO 300 J=LIM,NXSLOT      188
53 000434I      JM1=J-1                189
54 000442I      X(1)=DX*FLOAT(JM1)-0.5  190
55 000468I      Z(1)=1.0                191
56                                     192
57 000472I      DO 200 I=1,JM1          193
58 000486I      II=J-I                  194
59 000498I      IIM1=II-1               195
60 0004A6I      IP1=I+1                 196
61 0004B4I      X(IP1)=DX*FLOAT(IIM1)-0.5  197
62                                     198
63 0004E4I      TEST=X(IP1)+0.001        199
64 00051CI      IF(X(IP1).GE.XPSI(J,M)) GO TO 180  200
65 000548I      X(IP1)=XPSI(J,M)         201
66 00055AI      Z(IP1)=1.0              202
67 000566I      IPTS=IP1                203
68                                     204
69 00056CI      GO TO 201                205
70 00056CI      CONTINUE                 206
71 0005A4I      Z(IP1)=ZPSI(II,J,M)      207
72 0005B0I      IPTS=IP1                 208
73 0005C8I      CONTINUE                 209
74                                     210
75 0005C8I      CALL DRAW(Z,X,IPTS,441)  211
76 0005F4I      DO 250 I=1,NX1          212
77 000608I      Z(I)=-Z(I)              213
78 000626I      CONTINUE                 214
79 00063EI      CALL DRAW(Z,X,IPTS,441)  215
80                                     216
81 00066CI      CONTINUE                 217
82                                     218
83 000684I      CALL AXES(23.2,2,2 (DIMENSIONLESS WIDHT),24.1,  219
84      8,X (DIMENSIONLESS LENGTH))'  220
85      NN=NM*(M)                        221
86 000720I      CALL MODE(5,SAME,SAME,SAME)  222
87 000732I      CALL NOTE(2.8,8.2,'DELT =',6)  223
88 000750I      CALL NOTE(3.5,8.2,'DELT,1002)  224
89 000814I      CALL NOTE(2.2,7.9,'XSINK =',5)  225
90 000888I      CALL NOTE(2.8,7.9,'XSINK,1003)  226
91 0008CC I      CALL NOTE(3.4,7.9,'XSINK =',7)  227
92 000940I      CALL NOTE(4.2,7.9,'YSINK,1003)  228
93 000984I      CALL NOTE(3.0,7.5,'SLOT',4)  229
94 0009F8I      CALL NOTE(3.5,7.5,'NN,0)      230
95                                     231
96                                     232
97                                     233
98                                     234
99 000A3CI      Z(1)=-1.5                235
100 000A46I      X(1)=-0.5                236
101 000A50I      Z(2)=-1.0                237
102 000A5AI      X(2)=-0.5                238

```

INDICATE THE SOLID BOUNDARIES WHICH DELIMIT THE SLOT  
AND VOID NEAR THE MOUTH OF THE SLOT.

FORTRAN-VIID R04-00

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184

\*\*\*, SEE DOCUMENTATION PACKAGE, 04-101M99.

103	000A64I	Z(3)=-1.0	239
104	000A6EI	X(3)= 0.5	240
105	000A78I	Z(4)= 1.0	241
106	000A82I	X(4)= 0.5	242
107	000A8CI	Z(5)= 1.0	243
108	000A96I	X(5)=-0.5	244
109	000AA0I	Z(6)= 1.5	245
110	000AAAI	X(6)=-0.5	246
111	000A84I	CALL DRAW(Z,X,6,441)	247
112		C	248
113	000AE8I	CALL DRAW(0.,0.,1,9000)	249
114		C	250
115	000834I	IF(M.EQ.1) GO TO 50	251
116		C	252
117	000848I	RETURN	253
118	000B4EI	END	254

NO ERRORS:F7D R04-00 SUBROUTINE PLOTST 06/24/81 08:41:03 TABLE SPACE: 4 KB  
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 154 WORDS  
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> <i>(See instructions)</i>	1. PUBLICATION OR REPORT NO. NBSIR 83-2665	2. Performing Organ. Report No.	3. Publication Date May 1983
4. TITLE AND SUBTITLE  An Investigation of the Forced Ventilation in Containership Holds			
5. AUTHOR(S)  Howard R. Baum and John A. Rockett			
6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)  NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234		7. Contract/Grant No.	8. Type of Report & Period Covered
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)  U.S. Coast Guard 400 Seventh Street, SW. Washington, D.C. 20590			
10. SUPPLEMENTARY NOTES  <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)  An analysis of the fluid flow and mass transfer induced by ventilation systems in containership holds was carried out. The work was performed in support of the U.S. position before a committee of the International Convention on Safety to Life at Sea. The analysis consists of a detailed calculation of the forced motion through an interconnected set of narrow, stably stratified vertical air passages which represent an idealized containership holds the results of this calculation are then used in a study of the concentration boundary layers formed by the pickup of spill material assumed to lie at the bottoms of the air passages. The result is a set of formulae which determine the rate of extraction of spill material as a function of hold geometry, ventilation parameters, and ambient stratification. The results are incorporated in a computer program which is described in detail. A variety of computed results are presented, together with a listing of the program. The results indicate the crucial importance of locating the extractor as close to the hold bottom as technically possible.			
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)  Cargo ships; fires hazardous materials; modeling; stratified flow; ventilation			
13. AVAILABILITY  <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. <input checked="" type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161			14. NO. OF PRINTED PAGES  175  15. Price  \$16.00